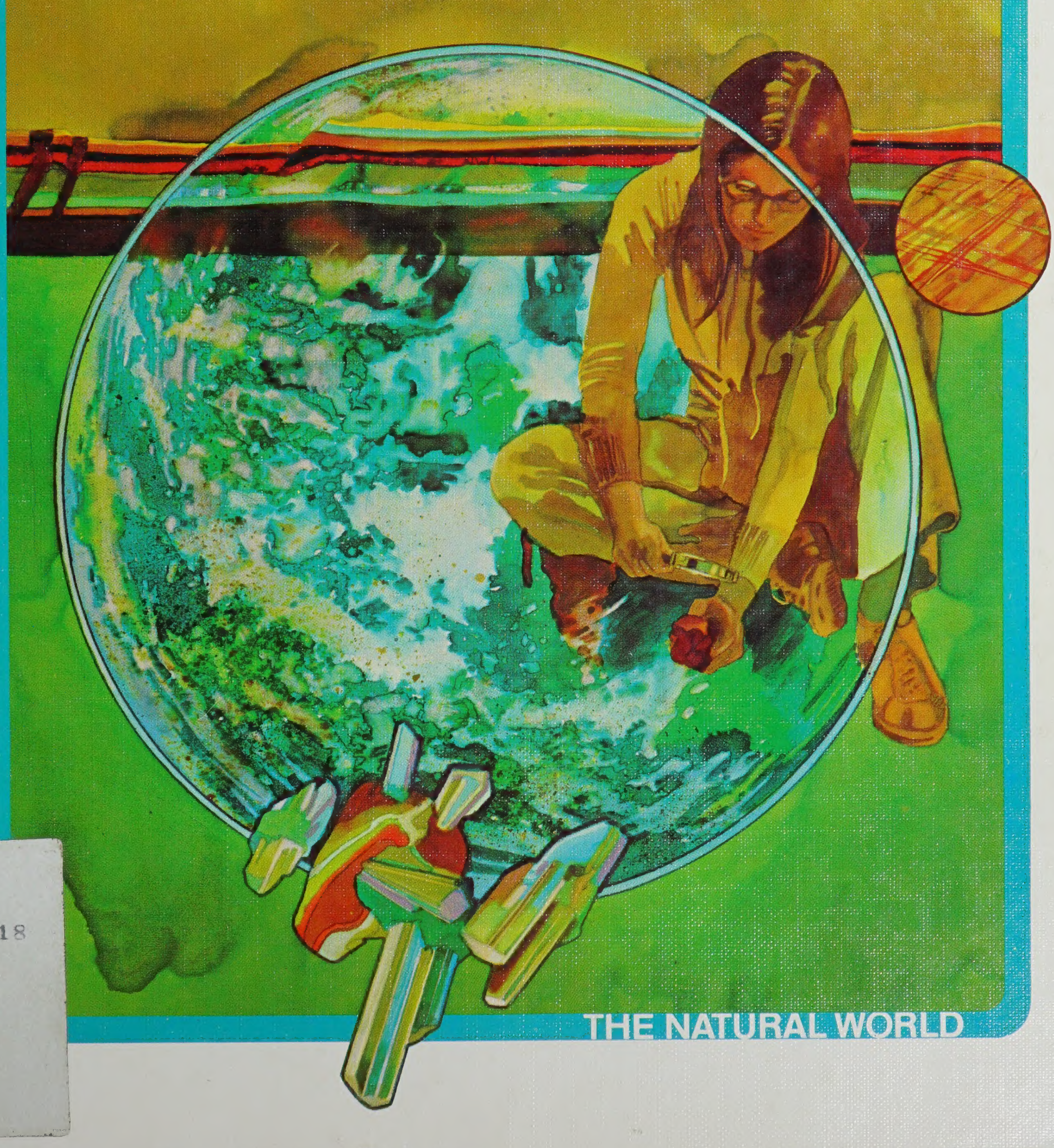
Teacher's Edition

Crusty Problems



THE NATURAL WORLD

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Crusty Problems

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THE NATURAL WORLD MODULES/LEVEL 3

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ACKNOWLEDGMENT

The Natural World/3 is an adaptation, by Silver Burdett Company and by the set of individuals listed on the previous pages, of the materials produced originally by the Intermediate Science Curriculum Study (ISCS) and copyrighted by The Florida State University under the title of *Probing the Natural World.*

 ISBN 0-382-04399-5

Introduction

These modules are quite unlike most materials used in science courses. The content, the approach, and the underlying objectives probably stand in sharp contrast to the books you are accustomed to.

This Teacher's Edition has been designed to help you help your students as they study this module. Parts A and B give a brief overview of the module and its objectives. Parts C and D provide some detailed information about equipment, local supply items, and safety. Marginal notes in the chapters idenitfy key questions, alert you to materials that must be prepared in advance, and suggest how to handle certain trouble spots. You may wish to add notes of your own as you work with this module.

The authors suggest that you read "A Brief Talk," in the introductory section of the student portion of the module, before you begin using the module in your teaching. And of course you'll want to make regular use of the Instructional Management Guide. It has all kinds of suggestions for making the best use of the modules, the Record Books, and the Resource Book.

PART A • OVERVIEW

Crusty Problems is concerned with the geologic aspects of earth science. It closely follows the format of the other modules in THE NATURAL WORLD series, with one major difference—*Crusty Problems* is organized into four distinct parts. The first part, "A World View," concentrates on the earth as a whole and should be done first. The remaining three parts may be done in any order. They deal with the formation, composition, and change of the three land zones in the United States—"The Mountains," "The Midlands," and "The Shorelands."

PART I: A World View

Chapter 1 introduces the earth as a dynamic body, as evidenced by earthquakes, continental drift, and sea-floor spreading. Students begin the process of using evidence to piece together explanations for the land features they see.

Excursion 1-1 helps the students visualize personal and key historical events in the perspective of geologic time.

Excursion 1-2 introduces the technique of comparing different regions by matching rock layers and shows how the presence of similar fossils on different continents supports the theory of continental drift.

Chapter 2 discusses the mechanics of sea-floor spreading. Earthquake patterns are presented as evidence of the mid-ocean ridge system and of the formation of new crust. This leads to a discussion of the plate theory. The chapter concludes by introducing the organization of the remainder of the module in terms of its three parts—mountains, midlands, and shorelands.

Excursion 2-1 is a remedial excursion that provides the background for understanding and measuring latitude and longitude.

PART II: The Mountains

Chapter 3 introduces the three major classes of rock—igneous, metamorphic, and sedimentary—in terms of their texture, composition, and process of formation. Identification is limited to major mineral and rock types and is by no means exhaustive.

Excursion 3-1 presents the students with key mineral specimens and introduces a simplified system for classifying them in terms of cleavage, hardness, and luster.

Excursion 3-2 provides an opportunity for the students to observe directly how layered sediments can form.

Excursion 3-3 outlines a step-by-step procedure for classifying rocks as igneous, metamorphic, or sedimentary on the basis of texture, composition, fossils, and chemical activity.

Excursion 3-4 uses a simulated field trip to demonstrate how collected rock samples can be used to identify areas of regional metamorphism. Students are also introduced to the technique of taking acetate peels to study rock texture.

Chapter 4 takes the students on a brief tour of the mountains in the United States, providing explanations of how these mountains formed. Models of uplift, erosion, and volcanism are used to illustrate the principal formative processes of mountain-building.

Excursion 4-1 uses simple clay models to illustrate the formation of dikes, sills, and domes from magma.

Chapter 5 concentrates on the role of glacial carving in shaping mountains. The processes of glacial motion and plucking are introduced, and the formation of cirques, tarns, and horns explained.

Excursion 5-1 outlines the process by which snow turns into glacial ice.

PART III: The Midlands

Chapter 6 describes how erosion and deposition contribute to the formation of the flat plains and gentle rolling hills typical of the midlands of the United States. River simulations, using a stream table, are extensively employed to teach the fundamental variables involved.

Excursion 6-1 introduces the students to the concept of braiding, produced by a barrier in a stream's path.

Chapter 7 extends the study of the effects of flowing water on a landscape. This chapter focuses on the relationship between the rate of stream flow and the stream's particle-carrying capacity. Wind erosion and deposition are shown in similar perspective.

Excursion 7-1 pinpoints the differences between gullies and canyons and the processes responsible for their formation.

Excursion 7-2 shows the effect of water traveling in a curved path and helps the student understand erosion and deposition at a river bend. This leads to an understanding of meandering streams, wide river valleys, and oxbow lakes.

Excursion 7-3 uses a stream table to demonstrate the factors leading to delta formation. The effect of sea level on delta formation is also introduced.

Excursion 7-4 simulates the formation of alluvial fans.

Excursion 7-5 develops a model for sand dune formation and movement.

PART IV: The Shorelands

Chapter 8 introduces the concept of energy associated with waves and the effects of wind and waves doing work on a shoreline.

Excursion 8-1 provides background for understanding the actual motion of the water particles in a wave.

Chapter 9 extends the development of shoreland features. The causes and effects of changes in sea level are examined, in conjunction with related changes in shoreline profile.

Excursion 9-1 is a simulation activity concerned with longshore drift and ways of retarding it.

Excursion 9-2 provides background information on the meaning of sea level and ways of describing and measuring it.

Chapter 10 interprets the past and future of a seacoast in terms of its predominant features.

Excursion 10-1 provides background on the origin and formation of beach sand.

Excursion 10-2 discusses the formation of fiords and estuaries.

PART B • MODULE OBJECTIVES

Chapter 1

- States the Wegener theory of continental drift.
- Identifies evidence supporting the theory of continental drift.

Chapter 2

- States what an epicenter is.
- Locates earthquakes on maps, using epicenter data.
- Relates earthquake activity and patterns to sea-floor spreading.

Chapter 3

- Identifies rock texture as interlocking or noninterlocking.
- Names factors that determine a rock's texture.
- Names three major classes of rock.
- States the conditions under which igneous rock forms.
- Describes the process by which sedimentary rock forms.

Chapter 4

- Identifies the principal processes of mountain-building.
- States how dome mountains are formed.
- Distinguishes between volcanic, folded, and dome mountains.

Chapter 5

- Identifies surface features that are glacial in origin.
- Describes the process of glacial carving.
- Describes conditions affecting the advance of glaciers.

Chapter 6

- Describes characteristics of river systems.
- Differentiates between kinetic energy and potential energy of river water.
- Identifies factors that increase a river's kinetic energy.

Chapter 7

- Identifies depositional features resulting from reduction of a stream's kinetic energy.
- Explains the gradation of particle size found in stream deposits.
- Explains how gullies form.
- Explains headward erosion.

Chapter 8

- Relates type of shoreline change to wave energy that produces it.

- Predicts effects of a hurricane on a beach.
- Identifies features associated with rocky or steeply inclined shores.

Chapter 9

- Explains mechanism for the formation of a sand beach.
- Identifies shoreline conditions that cause refraction and diffraction of waves.
- Identifies effects of longshore drift on beaches.
- Identifies wave-cut benches as evidence of erosion influenced by tides.

Chapter 10

- Describes how sandbars and spits are formed.
- Differentiates between fiords and estuaries in terms of the processes by which they were formed.

PART C • SPECIAL EQUIPMENT AND MATERIALS

Advance Preparations

1. Rock kit The rock kit contains 16 different kinds of rock, with 4 pieces of each kind. Each piece must be numbered before being put out for student use. Use white marking liquid to make a dot about 0.5 cm in diameter on each piece of rock. When the liquid dries, write the sample number inside the dot with a ball-point pen. Sample numbers are as follows: *Sedimentary rocks:* conglomerate (13), shale (16), limestone (17), sandstone (19). *Metamorphic:* gneiss (05), marble (12), quartzite (15), slate (18), schist (20). *Igneous:* pink granite (06), gray granite (07), gabbro (08), basalt (09), rhyolite (10), obsidian (11), pumice (14). *(Chapter 3)*

2. Mineral kit The mineral kit contains 13 different minerals, with 2 pieces of each kind. Each mineral sample must be numbered in the same way as the rock samples. The following numbers should be used: augite (21), calcite (22), microcline feldspar (23), plagioclase feldspar (24), galena (25), garnet (26), hematite (27), hornblende (28), biotite mica (29), muscovite mica (30), olivine (31), quartz (32), pyrite (33). *(Chapter 3)*

3. Hydrochloric acid (0.5M) Add 20 ml of concentrated (12M) hydrochloric acid (HCl) to 480 ml of water. Dispense in dropping bottles labeled "Dilute HCl." *(Chapter 3)*

4. Test-tube racks (quart milk cartons) (10) If test-tube racks are not available, you can make some out of plastic-coated, one-quart milk cartons. Cut out one side of the carton for the front of the rack. Make several cuts in the top side, large enough for a test tube to slide in. See diagram on page 36. *(Chapter 3)*

5. Chalk (3 white, 3 colored) Crush the white chalk and the colored chalk separately into a fine powder, and put in labeled baby-food jars on the supply table. *(Chapters 3, 7)*

6. Modeling clay A flat blade such as an old hacksaw blade will be useful in cutting the clay. The clay is furnished in assorted colors. Put a shoe box or other container on the supply table for each color. The clay should be separated by color at the end of an activity. *(Chapter 4)*

7. Volcano Detailed instructions for constructing a simulated volcano are provided on pages 65 and 66. It is suggested that only one volcano be set up per class, so that the activity can be done under close supervision. You may wish to do it as a demonstration. Best done in a semidarkened room, the activity gives a very realistic simulation of a volcano; be forewarned, however, that it is very messy to perform. The products of combustion of the ammonium dichromate include chromic oxide (Cr_2O_3), which is a dark-green fluffy substance. As with a real volcano, this ash is thrown into the air, and will be all over the room. Also, as with any pyrotechnics, this activity is potentially dangerous. *(Chapter 4)*

8. Sand dune box (5) Provide shoe boxes with one end cut out. Put a 1-cm layer of fine white sand in each box. *(Chapter 7)*

9. Fine white sand (450 g) This is a fine-quality sand for limited use only. Do not use for making up sand-silt mix. Set out in a baby-food jar labeled "White sand." *(Excursions 7-2 and 7-5)*

10. Sand-silt mix Fill a couple of baby-food jars with silt mix and label. Combine the remainder of the silt with enough sand (about 12 litres) to make about 14 litres of

Figure 1

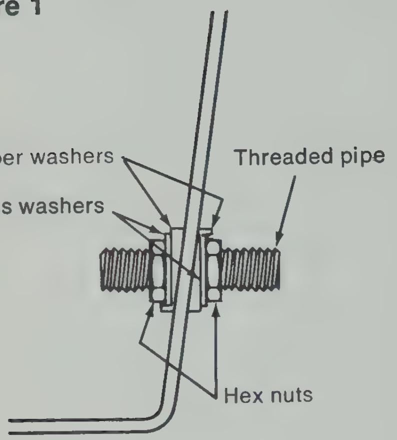
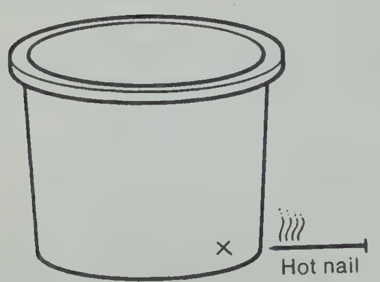


Figure 2



sand-silt mix. Put about 3.5 litres of the mixture in each stream table. The mix should be moistened before student use. *(Chapters 6–10)*

11. Stream-table kits (4) Each stream-table kit comes with the following items: the stream table itself (a large plastic pan with a hole at one end), 1 small threaded pipe, 2 nuts, 2 brass washers, 2 rubber washers, a 2-m length of plastic tubing, and a screw clamp. The following preparations should be done before the stream-table apparatus is put out for student use. *(Chapters 6–10)*

Outlet system. Insert the threaded pipe into the outlet hole at the end of the stream table. Secure the pipe with a rubber washer, a brass washer, and a nut on either side of the hole. (Figure 1 is a detailed diagram of this arrangement.) Cut a length of tubing equal to the distance from the stream table (at the height at which it will be used) to the floor. Slip the tubing over the end of the pipe, and attach the screw clamp at some distance from the pipe.

Supply system. Heat a large nail (quite hot) and push it through the side of a 5-litre pail, about 2 cm from the bottom, as shown in Figure 2. Make an opening just large enough for the threaded pipe supplied in the Pail-Fitting Package. (You can enlarge the hole by reheating the nail.) Smooth the inner and outer surfaces around the hole with a sharp tool. Do this for 4 pails. Then make a spout for each one, using the materials in the Pail-Fitting Package. Insert the threaded pipe into the hole in the bucket. Secure the pipe with the nuts and washers, as was done for the stream-table outlet (see Figure 1). Slide a 50-cm length of tubing over the end of the pipe and attach a screw clamp.

A diagram of the complete stream-table setup is shown on page 104. You may have to trim the tubing further to fit the particular conditions in your classroom.

Cleanup area. Provide a bucket of water in which students can rinse their hands when working with the stream tables. Mud should not be washed into a sink. Keep plenty of paper towels and a mop on hand.

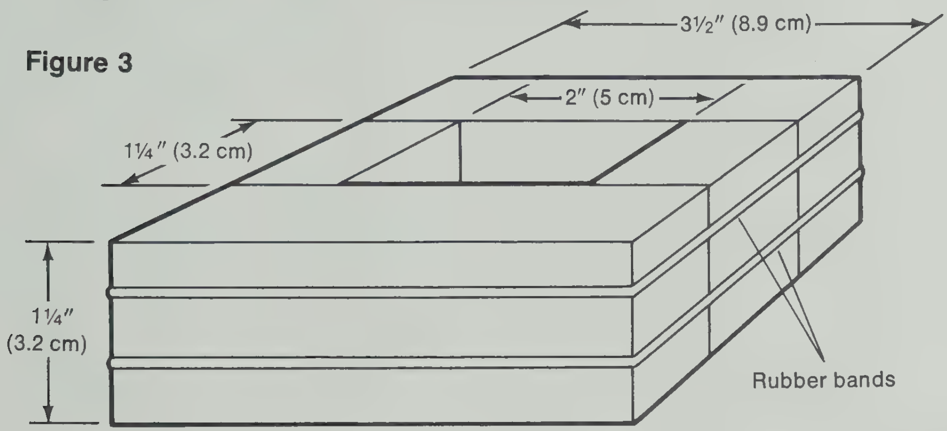
12. Plaster sheets (8) Cover the bottom of a flat dish—such as an aluminum baking pan—with a very thin layer of water. Sprinkle in plaster of paris to make a wet layer about 3 mm deep. When this mixture is almost set, cut through the

plaster to make strips about 5 cm wide. Allow these to set and dry completely. *(Chapter 7)*

13. Sand-and-plaster blocks (8) Although only one of these blocks is required per stream table, it is suggested that you make a total of 8 in order to have extras, since the blocks erode with use. *(Chapter 8)*

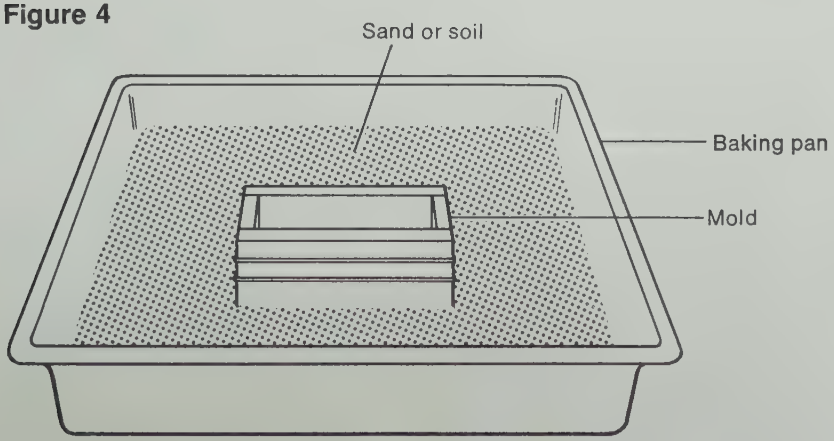
(a) Make a wooden mold as follows: Start with a strip of wood that measures approximately $9\frac{1}{2}'' \times 1\frac{1}{4}'' \times \frac{3}{4}''$ (24 cm × 3.2 cm × 1.9 cm). Cut the $9\frac{1}{2}''$ (24 cm) length into 4 pieces. Two pieces should be $3\frac{1}{2}''$ (8.9 cm) long. The other two should be $1\frac{1}{4}''$ (3.2 cm) long. Arrange the wood as shown in Figure 3. Note that the pieces are held together with rubber bands.

Figure 3



(b) Put a thin layer of sand or soil into the bottom of an old aluminum baking pan. Place the mold in the sand, as shown in Figure 4.

Figure 4



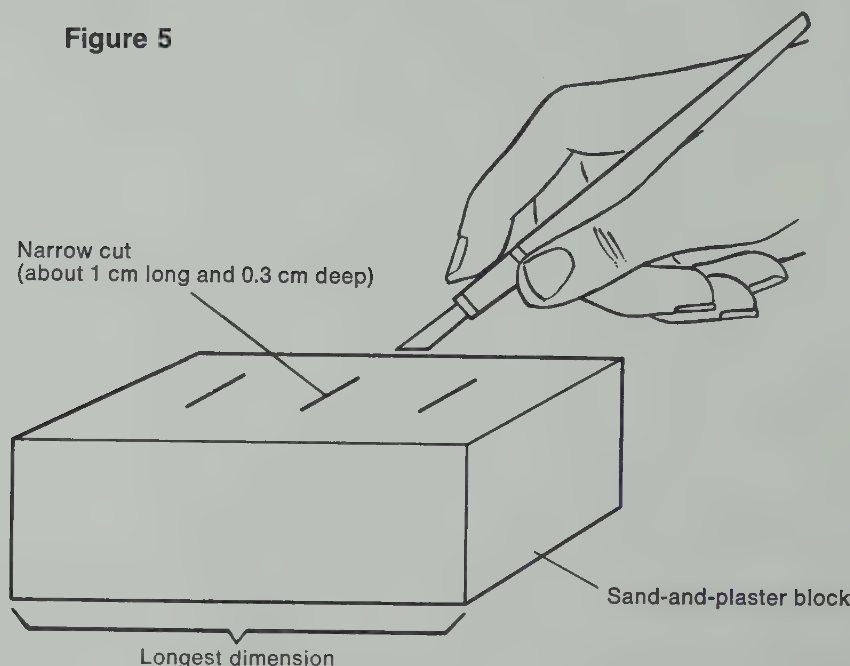
(c) Thoroughly mix 1 cup of plaster of paris with 3 cups of clean sand.

(d) Pour water into the mold until it is about half full. Quickly sprinkle in just enough plaster-sand mixture to fill the mold. If the material in the mold looks dry, sprinkle some water on top, but be careful not to make it too wet.

(e) Let the material in the mold set for about an hour. Then remove it from the mold. (You will probably find that the easiest way to do this is to dismantle the mold.)

(f) Make three small cuts in the sand-and-plaster block, as shown in Figure 5. The cuts should each be about 1 cm long and 0.3 cm deep.

Figure 5



(g) Any of the original, unused plaster-and-sand mixture can be stored in a tightly capped jar.

14. Plaster blocks (12) Each stream table will need one block 4″ × 1″ × 1″ (10 cm × 2.5 cm × 2.5 cm) and two blocks 4″ × 2″ × 2″ (10 cm × 5 cm × 5 cm), made of 100% plaster. Prepare molds of these dimensions, using the same procedure as for the sand-and-plaster blocks. Note that a different size of wood will have to be used for these molds, since the specified heights of the plaster blocks are different. This time add only plaster of paris and water to the

mold. The blocks will take about the same time (1 hour) to set. No notches need be made in the plaster blocks. *(Chapter 9)*

Local Supply List

Scissors
Colored pencils
Rulers
Tape
Baby-food jars (about 3 dozen)
Adding machine paper
Clock or watch with sweep-second hand
Paper
Test-tube racks or 10 1-quart milk cartons
Paper towels
10 glass plates about 1 cm square
  (cut from broken window glass)
Sharp knife
Old hacksaw blade
White chalk
Colored chalk
Teaspoons (may be plastic)
Small paper cups
Metal file
Fine sandpaper
Masonite or plywood board (25 cm × 25 cm)
4 bricks
Wooden matches
4 wooden blocks (such as 2 × 4's)
  about 1 ft long
Old aluminum baking pans
Sand (12 litres)
Gravel or small pebbles (1 litre)
Wax marking pencils
8 cardboard shoe boxes
20 pieces of cardboard (from old shoe boxes)
Wood for making molds (See **12** and **13**
  under Advance Preparations.)
Rags
Mop
Test-tube stoppers

PART D • SAFETY NOTES

There is potential danger any time matches or alcohol burners are used. Students should be reminded to exercise caution and pay close attention to what they are doing when working with any kind of flame. *(Chapters 3 and 4)*

Solid sulfur and naphthalene are melted in Chapter 3. It is important that this be done in a well-ventilated room. Students should wear safety goggles while heating these materials.

Dilute hydrochloric acid is used in Chapter 3 excursions. Although used in dilute form, the acid can burn the skin and damage clothing if not handled properly. Students should be cautioned to avoid spilling or splashing the acid and should be reminded to rinse their hands, the tabletop, and all materials that have come in contact with the acid.

The simulated volcano in Chapter 4 should be done only under close supervision. (See description under PART C.) Students should wear safety goggles in the vicinity of the volcano and should be cautioned to keep hair and face away from the cone.

NOTES

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Crusty Problems

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ISBN 0-382-04397-9

Contents


A Brief Talk

There are many ways to study science. No single way is the best for everybody. We've prepared this book, and others, to introduce you to science a bit at a time. We could have written a long book with many ideas and many chapters. Instead, we chose to present a few important things for you to think about in each of these books. And we've done it in such a way that you can *do* science activities—not just read about them.

To do science activities, you need equipment and materials. So we have asked that these be gathered together right in your classroom. Look around; you'll probably see some of them.

Getting What You Want

Each book like this one has a purpose. The title will give you some idea of what's inside. But to get a better idea of what's there, thumb through the pages. See what activities you'll be doing and the kind of equipment you'll be using.

First, you'll have a say in choosing the modules you want to study. Second, you can choose to do, or not to do, some of the activities within each module. These activities are called Excursions. Third, you can get help with your own special problems by doing other short activities. These activities are called Resources. You'll find them in the *Resource Book.*

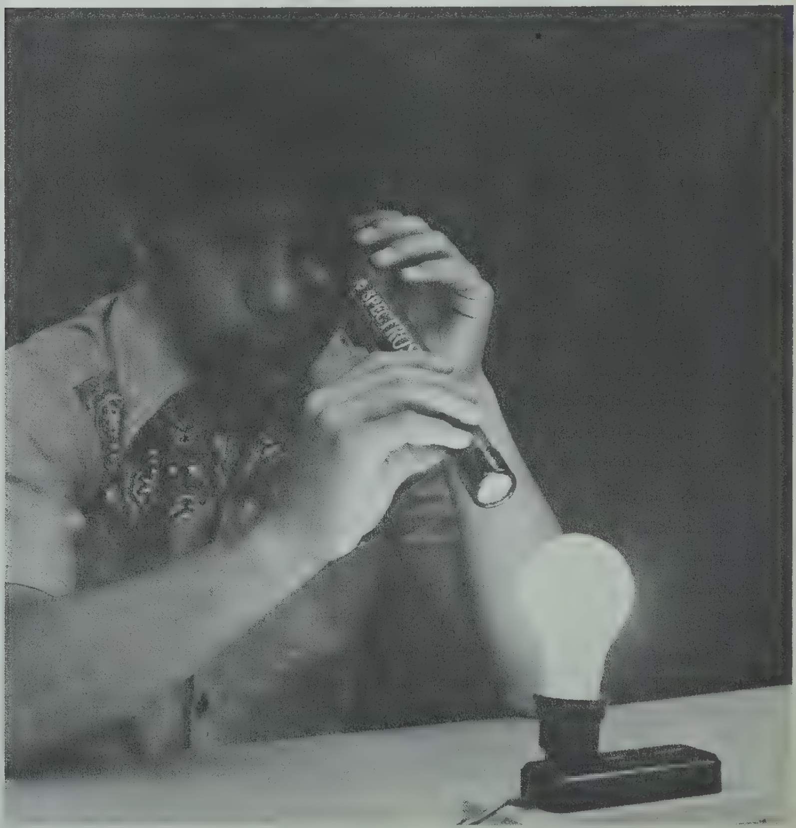
Fourth, you can check up on your own progress, Self-Evaluations are provided for each module chapter. You'll find them in the *Record Book.* And you'll find their answers there, too.

Working on Your Own

Your science class may be quite different from your other classes. This book, and others like it, will guide your study of science. Your teacher will not direct all your work. You'll be responsible for your progress. You'll also be responsible for taking good care of equipment and materials.

Begin each day's work where you left off the time before. Try to work ahead on your own or with your partner, if you have one. If you meet problems you can't solve, get help. But don't expect your teacher to give you the answers to the questions in the book.

After a few days, some of your classmates who are using this module may be ahead of you. Others may be behind. And other students will be studying different modules. This is how the course is supposed to work. No prizes will be given for being the first to finish a module. Work at a pace that is best for you. But be sure you understand what you have done before moving ahead.



Safety in the Laboratory

This module will allow you to do several experiments. If you do them properly, they are perfectly safe. There are instructions and drawings to help you do each of the activities. But you should also observe the following rules:

- Equipment and chemicals should be used only in the classroom, unless your teacher gives you permission to use them elsewhere.
- Your work area should be left clean. Clean all equipment after use and return it to the supply area.
- Handle all chemicals carefully. Keep them away from your eyes, ears, nose, mouth, clothing, and skin.
- Read labels. Use chemicals only from containers that are clearly labeled.
- Wipe up spills with damp paper towels.
- Report any accidents immediately to your teacher.
- Throw waste materials into the proper containers.
- Wash your hands at the end of each laboratory period.
- Goggles should be worn when you are working with chemicals, when you are heating materials in test tubes, or when you could be harmed by flying objects.

What You Are Expected to Learn

During the year, you will work much as a scientist does. You should learn some useful information. More important, we hope that you will learn how to ask and answer questions about nature. Keep in mind that learning how to find answers to questions is just as valuable as learning the answers themselves—maybe even more valuable.

Do not write in this book unless it belongs to you. Do all your writing in your *Record Book*. Use your *Record Book* to check your progress with the Self-Evaluations.

From time to time, you will find that your answers to questions aren't the same as those of your classmates. Don't let that worry you. There are several right answers to some questions. And some questions may not have a correct answer. This may disappoint you at first. But soon you'll realize that there is much in science that isn't yet understood. So in this course, you will learn some things we don't know as well as some of the things we do know.

PART I
A World View

A First Look at the Earth

Excursions 1-1 and 1-2 are keyed to this chapter. Note that they are found at the end of the chapter.

1

CHAPTER EMPHASIS

The earth is a dynamic body, as evidenced by such large-scale changes as earthquakes, continental drift, and sea-floor spreading.

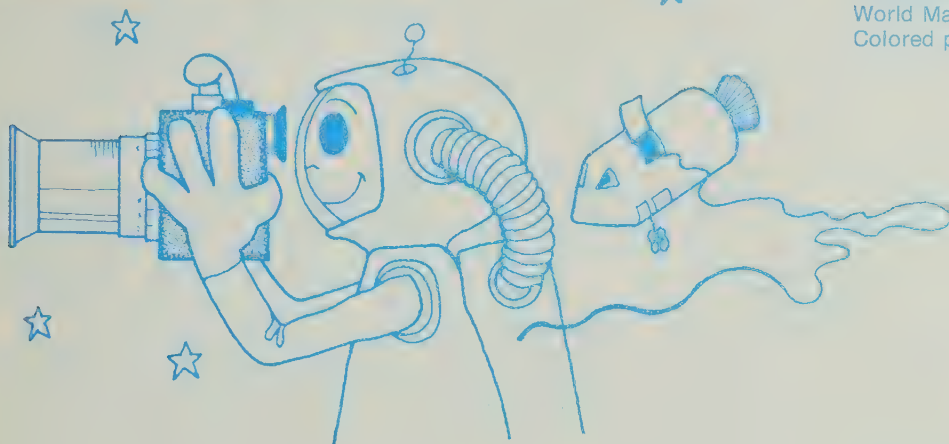
FILMSTRIP KEY

Enrichment
Continental Drift

EQUIPMENT

Per student-team

1 scissors
World Map (in Record Book)
Colored pencils



Just a few years ago the photograph you see on the facing page could not have been taken. Isn't it rather awesome to think you were walking around on that planet the day the photograph was taken? In this module you will be asked to solve many problems concerning the planet you are looking at. You'll make observations of features that you may see, determine how those features were formed, and what might happen to them in the future.

Although you have lived on the earth all your life, there is a good chance that you have wondered about one or more of the following.

1. How old is the earth?
2. Has the earth always looked the way it does on the facing page?
3. Has the land that your school rests on always been there?
4. Is the earth changing in any way?
5. Do the continents actually drift?
6. What causes an earthquake, a volcano, and a landslide?

MAJOR POINTS

1. Observations of the earth from different locations (outer space, an earth satellite, on the surface) vary and lead to different interpretations.
2. The earth is a changing planet.
3. The shape of the continents led early geologists to hypothesize continental drift.
4. The occurrence of glacial drift and grooves in the Southern Hemisphere continents and India are correlated and support the drifting-continent hypothesis.

Encourage students to follow this suggestion of writing in their Record Book the questions for which they have no answers. This is an excellent opportunity to stress the sound scientific concept of asking the right questions, and then searching for answers to them.

Have you ever thought about any other questions related to the earth? If so, why don't you write them in the space provided in the Record Book? Then as you study this module, or when you finish, check back and see if you've answered them.

Before moving in and getting a closer look at the earth, examine the chapter-opening picture once again.

☐ **1-1.** If you were an observer from outer space, how would you describe the planet before you?

Figure 1-1

Figure 1-1 shows a portion of the planet as seen from about 240 kilometres above the surface.

☐ **1-2.** List the important features you see in the photograph.

☐ **1-3.** In the photograph, do you see any evidence of motion or change?

Figure 1-2

DOWN TO EARTH

If you said No in response to question 1-3, your answer is correct, based on the evidence in the picture.

☐ **1-4.** What would you say if asked the same question about Figure 1-2? If you decided that change is shown in the photograph, list the evidence you used to make that choice.

From the evidence in Figure 1-2, there's no doubt that at least part of the earth is active and changing. One of the exciting areas of study a geologist encounters is the ways the earth has changed through time and what might have caused the change. For an idea of the long period of time involved, try **Excursion 1-1,** "Geologic Time."

EXCURSION

DRIFTING CONTINENTS

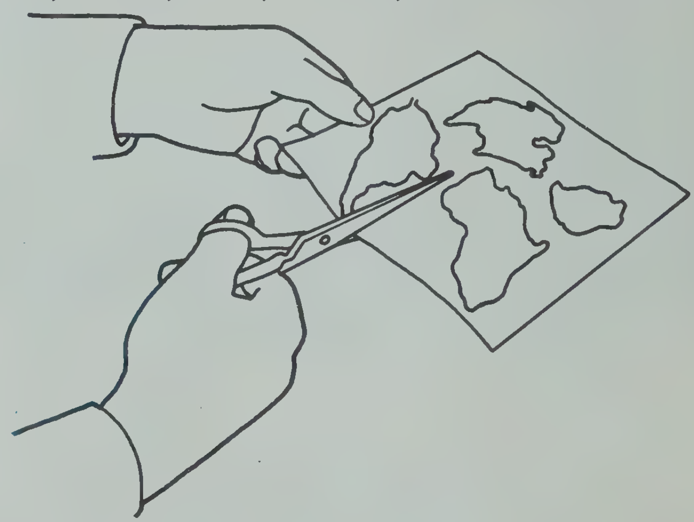
The single supercontinent that made up the earth according to the continental drift theory was called Pangaea. This huge mass split into two parts—Laurasia and Gondwana. The first of these became North America, Europe, and Asia. The second contained the land that through the ages became South America, Africa, Australia, Antarctica, and India. At a much later time, India drifted north to join the Eurasian continent.

For a moment let's consider the subject of change on a grand scale. In 1915 Alfred Wegener, a German scientist, proposed that all the continents were once joined together and formed one superlandmass. He also proposed that this landmass later broke apart into separate continents. This theory is known as *continental drift*. One of the first lines of evidence to suggest such an idea is the shape of the continents. Try your hand at fitting the continents together as you would a puzzle. For the activity, you will need the following materials.

There is more than one map of the world in the Record Book. Be sure students cut out the one that pertains to Chapter 1.

1 pair of scissors
1 map of the world (from your Record Book)

ACTIVITY 1-1. Cut out the continents of North America, South America, Eurasia, Africa, Australia, and Antarctica.



Students should not expect a perfect fit. Many things could happen to shorelines to change their shape.

ACTIVITY 1-2. Piece the continents together in such a way that you get the best fit possible.

If you were successful, you probably were able to put the pieces of the puzzle together to form a supercontinent. Now suppose someone were to ask you if the continents were really together once. What would you say? What kind of information would you need to support the idea?

Below you will find the kind of information that an earth scientist might use. Earth scientists make observations of

the earth's features and use these to explain what they think happened long ago. They often study solid rock that is exposed on the earth's surface. Such rock is called an *outcrop*. Figure 1-3 shows a rock outcrop that is rather smooth in appearance and has a series of parallel grooves.

☐ **1-5.** What evidence is there that a powerful force was exerted on the rock shown in Figure 1-3?

Figure 1-3

If you know anything about the hardness of rocks, you'll probably agree that whatever scratched the rock in Figure 1-3 must have been a very powerful force. We know now that such grooves can be made by a huge sheet of ice, several thousand metres thick, moving very slowly over solid rock. Such sheets of ice are what we call *glaciers*.

A glacier carries, at its base, rock fragments of various sizes that act as an abrasive, like sandpaper. Thus, as the glacier moves along, it is capable of scratching and cutting deep grooves in the rock.

☐ **1-6.** What can you tell about the direction the glacier must have moved to carve such grooves as in Figure 1-3?

Geologists of the late nineteenth century used these grooves as evidence that an ice age existed about 200 million years ago.

Figure 1-4

Other evidence of an ice age is the location of deposits similar to that shown in Figure 1-4. Notice that the material contains rocks of various sizes, from large boulders to small fragments. Also, note that there is an abundant supply of finer material, such as sand, mixed in with the mass of rock. This is a typical feature of glacial deposits. Such a deposit is called *glacial drift*. River or stream deposits are more uniform in size because of the sorting effects of moving water.

Figure 1-5

Glacial grooves and glacial drift of about the same age have been found in South America, South Africa, Australia, Antarctica, and India! Figure 1-5 shows the distribution of ancient glacial drift and the direction in which glaciers moved. (The direction of glacial grooves tells geologists the direction in which the glaciers moved.) Look at South America closely. In order to explain the glacial grooves there, it would be necessary for the glacier to have moved from areas now covered by an ocean. Also, note that glacial drift is found very near the equator in Africa.

Students will have further experience with glacial grooves in Chapter 5.

One explanation of these facts is that the landmasses were connected at the time of glaciation and then the continents moved apart at a later time.

ACTIVITY 1-3. Using the cutouts of the continents from Activity 1-2, draw the arrows showing the direction of glacial motion on each of your cutout continents, as shown in Figure 1-5. Use a colored pencil to show the distribution of drift. Fit the continents together, using as guides the direction of the arrows (assume the glacier moved out in all directions from a central area) and the distribution of drift.

☐ **1-7.** Do you think the distribution of glacial drift and the location of glacial grooves provide evidence to support, or reject, the idea of continental drift? Explain your answer.

☐ **1-8.** If not, what other explanation can you make?

Matching glacial grooves and drift are not the only evidence. The presence of certain fossils and the similarity of rock layers provide additional evidence. **Excursion 1-2**, Rock Layers, Fossils, and Continental Drift,'' shows more about this.

EXCURSION

Before going on, do Self-Evaluation 1 in your Record Book.

Excursion 1-1
Geologic Time

EQUIPMENT

Centimetre ruler
Metrestick
5-metre length of adding machine paper

PURPOSE

To help students visualize different events in geologic time.

MAJOR POINTS

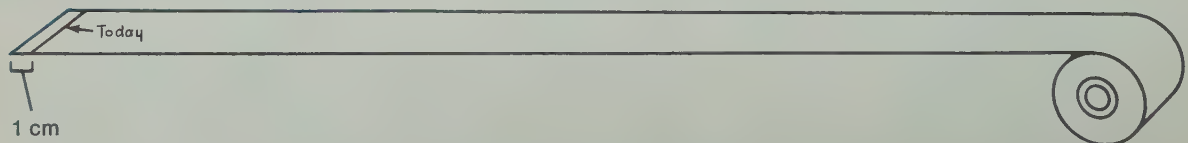
1. Some features of the earth result from events that occurred more than 3 billion years ago.
2. The appearance of human beings is a relatively recent event in geologic time.

What is a long time? Living to be eighty years old? The age of the United States? The span of human existence on the earth? Compared with the age of the earth, any of those is almost no time at all.

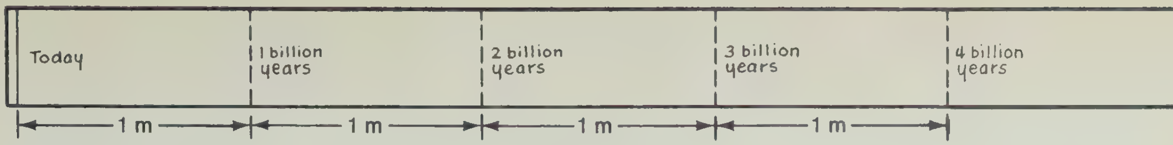
Some of the events that shaped our landscape can be traced back over 3 billion years. And that is a long time. This excursion gives you a graphical way of visualizing how long 3 billion years is.

All you need is:
Centimetre ruler
Metrestick
5-metre length of adding machine paper

Adding machine paper can be purchased in office supply stores.



ACTIVITY 1. About 1 cm from one end of the strip, draw a straight line as shown. Label it "Today."



ACTIVITY 2. Starting from the "Today" line, mark four dotted lines across the strip, each 1 m apart. Label the first dotted line "1 billion years," the second "2 billion years," the third "3 billion years," and the fourth "4 billion years."

ACTIVITY 3. From the 4-billion-year line, measure 50 cm farther down the strip. Draw a solid line across the tape at this point, and label as shown.

There is certainly some question about the exact date of the earth's beginning. However, there is a good basis for inferring that it was about 4.5 billion years ago. Table 1 shows some other events and how long ago scientists believe they occurred.

Table 1

Event	Estimated time since occurrence (in billions of years)
Oldest known rock	3.3
First abundant animal fossils	0.6
First reptiles	0.3
First primitive horses	0.07
First human beings	0.002
Last ice age	0.000 01
Earliest written records	0.000 005
Your birth	0.000 000 015

ACTIVITY 4. Using your metrestick, plot and label the times of the first four events listed in Table 1. (Remember, you are using 1 m to represent 1 billion years. Therefore 0.3 billion years should be plotted as 0.3 m, or 30 cm from the "Today" line on your tape. 0.07 billion years should be plotted as 7 cm.)

Plotting the time of the first human beings can be done as follows: Since 0.02 billion years would be plotted at 2 cm from the "Today" line, 0.002 billion years would have to be plotted at 0.2 cm, or 2 mm, from the "Today" line.

ACTIVITY 5. Plot and label "First human beings" on your paper tape.

☐ **1.** If you plotted the last three events in Table 1 on the paper tape, could you tell them apart? Explain.

☐ **2.** According to the scale you used to plot time, how many years does the width of your pencil point represent?

☐ **3.** Is your age a significant part of geologic time? How about the age of the United States?

1. No. The scale is such that times of these events can't be distinguished.

2. About 0.001 billion years

3. No. (You may wish to remind students, however, that significant changes *are* occurring in our landscape within these periods of time. Dramatic changes can occur even within a single day: e.g., during a flood or the eruption of a volcano.)

Excursion 1-2

Rock Layers, Fossils, and Continental Drift

EQUIPMENT

Ruler or other straightedge

PURPOSE

To show that rock layers and the presence of similar fossils are evidence in support of the continental drift theory.

Do you think the rock layers on the left side of the highway in Figure 1 match the rock layers on the right side? Compare the areas at the ends of the two lines AA′ and BB′. They should help you conclude that the layers do match.

You shouldn't be surprised, because engineers blasted the rock away to build the highway. However, the photograph illustrates one of the things that geologists do: namely, try to match rock layers that are separated from each other.

Figure 1

Let's look further at the idea of matching rock layers.

☐ **1.** Can you match any rock layers shown in Figure 2?

MAJOR POINTS

1. Geologists can compare different regions by matching the sequences of rock layers.
2. Fossils aid in the matching of rock layers.
3. The presence of identical fossil plants on different continents is strong evidence in support of the theory of continental drift.

Figure 2

The problem of matching is a little more difficult in this photograph. If you use a ruler, you should be able to find several layers that match (based on the color of each layer). Start with a layer that stands out from the others. Look for a layer of similar width and color in another column of rock. You can use a ruler to help you line up the layers. To understand how to do this, look at Figure 3.

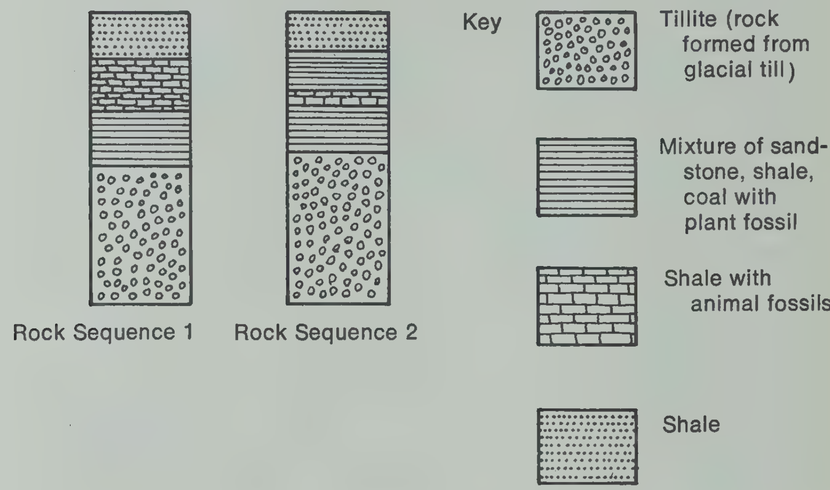
Figure 3

Figure 4 shows diagrams of two sequences of rock layers. All the rocks are layered. A key is provided to help you identify the rocks.

☐ **2.** Are the layers in rock sequence 1 in the same order as the layers in rock sequence 2?

☐ **3.** What else is different in the two sequences?

Figure 4

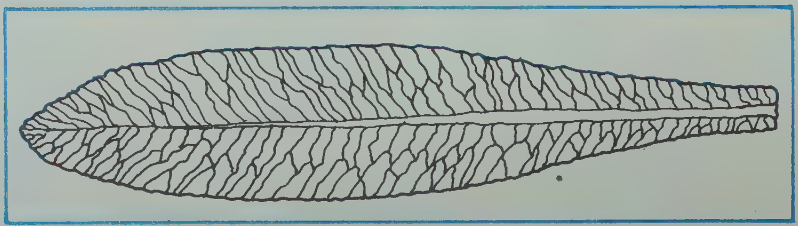


You probably found that the bottom three layers in each sequence matched. The lowest layer is tillite. Above that is a layer that has a mixture of sandstone, shale, and coal with a plant fossil. The third layer is shale with animal fossils. The fourth layer in sequence 2 is a mixture of sandstone, shale, and coal, which appears to be missing in sequence 1. However, the fifth layer in sequence 2 matches the top layer in sequence 1. The two layers are very similar.

Let's examine those sequences again. Figure 5 shows a drawing of the plant fossil found with the layer of sandstone, shale, and coal. Geologists use fossils to help them match rock layers. In fact, the presence of a certain

Figure 5

The seed fern *Glossopteris*, shown here, must have flourished in great abundance in the Southern Hemisphere some 200 million years ago, as evidenced by the profusion of fossil remains.



type of fossil is a better clue that the layers match than is the type of rock. Notice that the layer containing this plant fossil, which is called *Glossopteris,* lies just above the tillite.

Here's one more fact that might be helpful. Rock sequence 1 in Figure 4 is found in southern Brazil and rock sequence 2 is found in South Africa!

☐ **4.** What two clues indicate that land in two different parts of the world may have originally formed in the same place?

☐ **5.** How can you explain the occurrence of similar rock layers and identical fossil plants on two different continents?

Probably the strongest kind of evidence to support continental drift is the presence of identical fossil plants, such as *Glossopteris,* on different continents separated by thousands of kilometres of ocean. Identical plants could hardly have developed in areas separated by such distances. It is possible that the seeds of those plants could have floated across the ocean, but most biologists rule this out. You may suggest that birds carried the seeds. However, the first flying animals did not occur until millions of years after this time. Thus, the idea of continental drift was supported on the basis of similar rock layers and fossils occurring on different continents.

You might be wondering whether similar sequences and the fossil plant *Glossopteris* have been found elsewhere. Well, they have! They were found in Australia, India, and Antarctica!

Other Views of the Earth

2

EQUIPMENT

Colored pencils

FILMSTRIP KEY

Enrichment
Continental Drift

Excursion 2-1 is keyed to this chapter

Let's take another view of our ever-changing earth. You probably have never experienced the shock waves produced by an earthquake. But you have probably read about, or seen on television, some of the tremendous destruction caused by earthquakes. You might think earthquakes are rare events on the earth, especially if you have never experienced one. But this is not true. Hundreds of tremors occur daily all around the earth, many too small to be reported. Now and then, however, one occurs that is powerful enough to destroy cities and towns and kill thousands of people.

Let's consider what has been said. If there are many quakes occurring daily, why would we say that few of you have experienced them? Where do they occur? How deep in the earth do they originate?

Although earthquakes originate deep in the earth, they are usually described in terms of the corresponding point on the surface of the earth. This point is called the *epicenter* of the earthquake. Page 16 has an earthquake data table, which gives you information regarding the date, time, location, depth, and magnitude of some earthquakes. If you read across a single line in Table 2-1, you are obtaining information about a single earthquake.

PURPOSE

To examine earthquake patterns and the mechanics of sea floor spreading as evidence of global change To introduce the organization of the remainder of the module in terms of three types of geological regions—mountains, midlands, and shorelands.

MAJOR POINTS

1. Shallow earthquakes follow a pattern around the earth.
2. The system of shallow earthquakes outlines the mid-ocean ridge system.
3. One theory is that the earth's crust is separated into plates that can spread apart or slide together.
4. According to this theory, new crust is being formed at the mid-ocean ridges and is spreading away in opposite directions.
5. At other places the older crust is sinking back into the earth.

EARTHQUAKE DATA TABLE

Day	Hr	Mn	Sec	Lat	Long	Region and Comments	Depth (km)	Magnitude
February 1971 Origin Time (Greenwich Mean Time)				Geographic Coordinates				
1	01	12	26.8	37.2° N	30.2° E	Turkey	35	4.5
1	02	47	51.6	7.0° N	73.1° W	Northern Colombia	140	4.3
1	03	51	45.4	5.1° S	151.1° E	New Britain Region Felt (III) at Rabaul.	110	5.0
1	05	19	23.4	51.7° N	172.9° W	Andreanof Islands, Aleutian Is. Mag. 6 (Pas).	40	5.5
1	06	14	50.2	25.5° S	176.8° W	South of Fiji Islands	44	5.4
1	07	36	54.4	51.9° N	172.9° W	Andreanof Islands, Aleutian Is.	48	3.9
1	07	50	10.7	38.7° N	14.1° E	Sicily	N*	4.3
1	11	56	29.8	5.4° S	146.0° E	East New Guinea Region	73	
1	12	26	55.6	44.6° N	7.5° E	Northern Italy Felt (III) in Côte d'Azur.	18	4.4
1	12	48	32.8	56.2° S	27.4° W	South Sandwich Islands Region	17	5.1
1	14	21	42.9	42.3° N	85.3° E	Northern Sinkiang Prov., China	N*	4.8
1	14	43	26.6	2.9° S	139.1° E	Near N. Coast of West New Guinea	46	
1	14	56	23.1	6.2° S	154.6° E	Solomon Islands	103	5.4
1	14	59	12.6	62.3° N	145.7° W	Central Alaska	15	4.6

*"N" in the depth column means "normal." It should be considered a shallow earthquake.

Table 2-1

Magnitude refers to the so-called Richter scale, a scale ranging from 0 to 10, that is used to classify earthquakes. The largest magnitude recorded on the scale since its use was 8.6. The Alaskan quake of 1964 registered 8.4.

2-1. a. Date—Feb 1, 1971, at 1:12:26.8 (A.M.), Greenwich Mean Time.
b. Location—Turkey
c. Depth—35 km
d. Latitude—37.2° N
e. Longitude—30.2° E

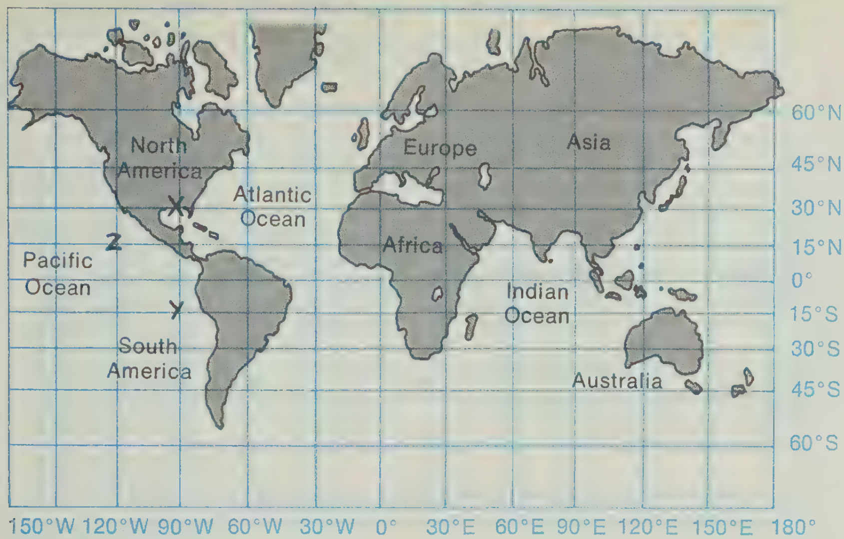
☐ **2-1.** To make sure you can read the table, determine the following for the first earthquake listed.

a. Date earthquake occurred
b. General location
c. Depth (km)
d. Latitude
e. Longitude

If you had trouble with this, ask your teacher for help before you continue.

To locate each earthquake on a map requires the use of two coordinates. That's why latitude and longitude are given in Table 2-1. They are the coordinates. For example, in Figure 2-1, the coordinates of point X are latitude 30° N, and longitude 90° W. The coordinates of point Y are latitude 15° S and longitude 90° W.

Figure 2-1



If you are not sure what latitude and longitude are or how they are measured, try **Excursion 2-1**, "Latitude and Longitude."

EXCURSION

☐ **2-2.** What are the coordinates of point Z?

Did you get latitude 15° N and longitude 120° W?

Table 2-2

Earthquake	Depth (km)	Symbol or Color
Shallow	0–69	+ blue
Intermediate	70–299	○ red
Deep	More than 299	● yellow

The colors in Table 2-2 are only suggestions. Students could also use a regular pencil, a pen with blue ink, and another colored pencil or pen.

ACTIVITY 2-1. The first earthquake listed in Table 2-1 has the coordinates 37.2° N and 30.2° E. This is shown on the map on page 18. Find the same location on the map in your

Record Book. Mark it with a plus. Plot the next five earthquakes listed in Table 2-1. The rest have been plotted for you. Use different symbols for shallow, intermediate and deep earthquakes. (Table 2-2 will tell you which range an earthquake is in.)

☐ **2-3.** On the basis of the earthquakes you have just plotted, list the regional locations of the earthquakes.

A pattern of earthquake occurrence should be evident from the plottings. Students should be able to recognize the ring around the Pacific Ocean, the concentration around the Malay Peninsula, the islands of the South Pacific and Japan, and a line running up the center of the North and South Atlantic and through the Mediterranean, between Eurasia and Africa, extending north of India through the Himalayas. The important thing is for students to see that they are not randomly distributed (question 2-4), but are definitely in zones. There is a concentration of shallow earthquakes through the Mid-Atlantic, and of intermediate to deep earthquakes along the western coast of South America.

☐ **2-4.** Would you say that earthquakes are randomly distributed over your map, or are they concentrated in zones?

Look over your completed map again but, this time, focus on the depth of the earthquakes.

☐ **2-5.** Can you find any zones on your map where there are concentrations of shallow, intermediate, or deep earthquakes? If so, where?

You have completed an exercise in which you plotted the location of many earthquakes. Geologists have been collecting similar data for years and have compiled the data as you did when you plotted the earthquakes. Figure 2-2 is a world map showing the distribution of earthquakes.

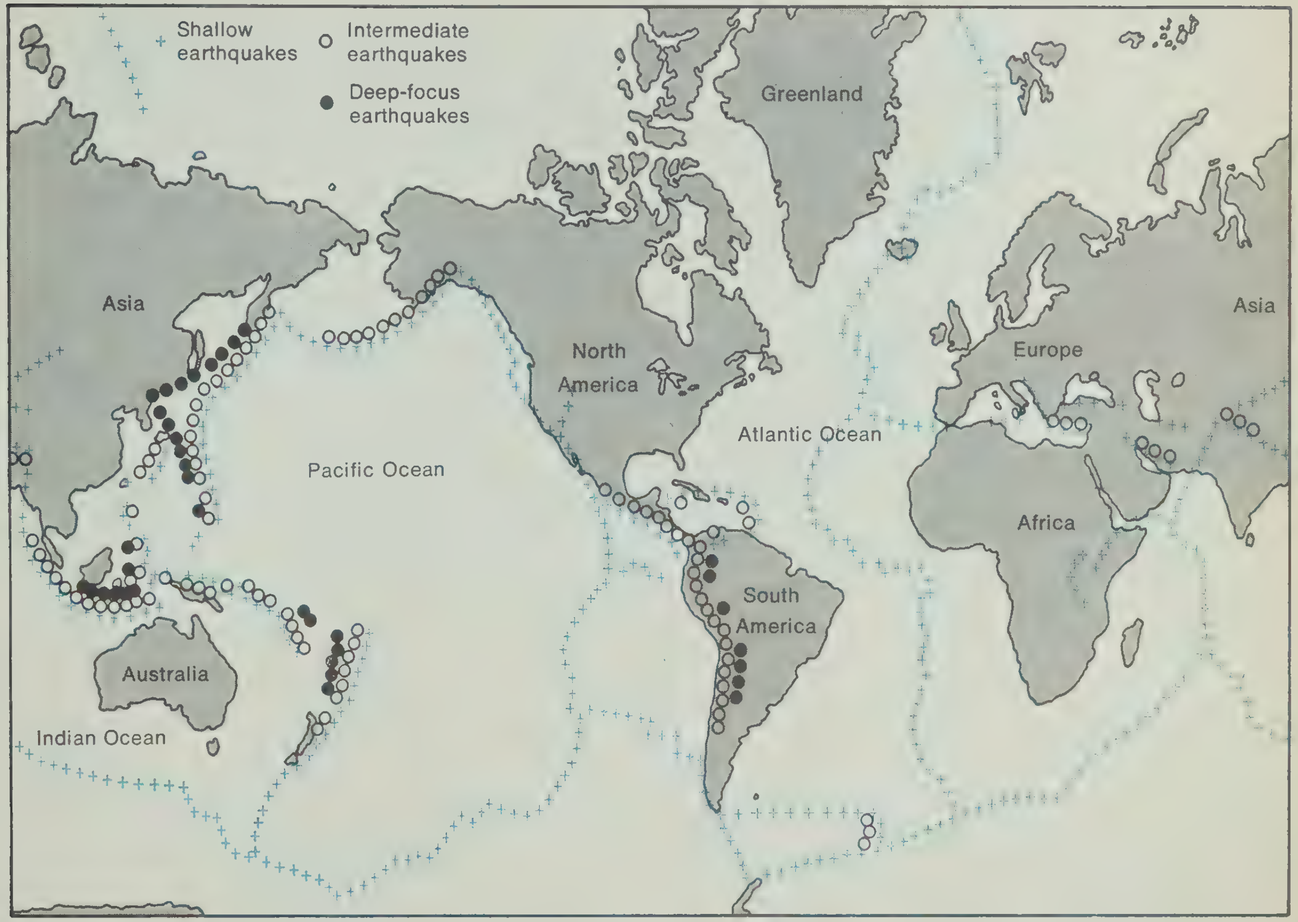
Note that the earthquakes are restricted to zones or belts and are not evenly distributed on the earth.

☐ **2-6.** In the region between South America and Africa, are the earthquakes shallow, intermediate, or deep?

☐ **2-7.** How deep are the earthquakes that occur along the western coast of South America? (Give a range of depths.)

☐ **2-8.** Identify two other areas where intermediate and deep earthquakes occur.

Figure 2-2



You should have noted that there is a zone of shallow earthquakes in the middle of the Atlantic Ocean. In fact, if you glance back to the map, you can trace the shallow earthquakes around the earth. This system of shallow earthquakes is known as the mid-ocean ridge system and consists of a chain of volcanic mountains. Shallow and deep earthquakes occur along the boundaries of oceans and continents (such as South America and the Pacific Ocean) or between two continents (Africa and Europe).

How can this pattern of earthquakes be explained? One theory states that the earth's crust is not all one piece. Rather, it is separated into plates that are spreading apart in some places and coming together in others. Earthquakes are most likely to occur in areas near the boundaries of the plates.

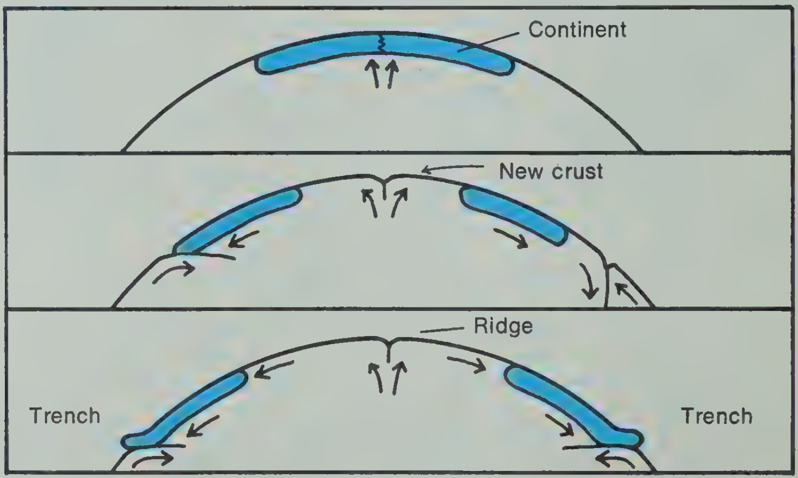
According to the theory, new crust is being formed at the mid-ocean ridges. This means new rocks are formed there.

2-9. The rocks should get progressively older, the farther they are from the ridge.

☐ **2-9.** Knowing that the crust spreads out from a ridge on either side, what can you say about the age of the rocks near the continents, compared with the age of the rocks near the ridge?

Scientists believe the ocean floor in the Atlantic is spreading slowly away from the mid-ocean ridge. This would suggest that the Atlantic Ocean now occupies an area between two continents that have split apart. South America is on one side and Africa is on the other. Figure 2-3 represents a simplified explanation of this theory.

Figure 2-3



Scientists have made tests to determine the approximate age of rocks beneath the ocean floor. They have, in fact, discovered that the farther the rocks are from a mid-ocean ridge, the older they are. This supports the theory of the spreading ocean floor. In addition, the scientists believe the pattern of earthquakes along a mid-ocean ridge outlines a huge crack in the earth's crust.

☐ **2-10.** How are earthquakes produced at the mid-ocean ridge, according to the plate theory of the earth's crust?

LOOKING AHEAD

Up to this point, you have viewed general changes that occur over the earth as a whole. For the rest of the module, you will study changes that go on in specific areas. You will see how various features got the way they are.

Take a look at the general geology diagram in Figure 2-4. If you look closely, you should find that part of the diagram contains features somewhat like those near you. Students all over the United States will find this to be true because the drawing includes most of the important landforms in this country. Notice that the drawing is divided into three sections—mountains, midlands, and shorelands. The remainder of this module is also divided into three sections. Each part will deal in detail with one section of the drawing.

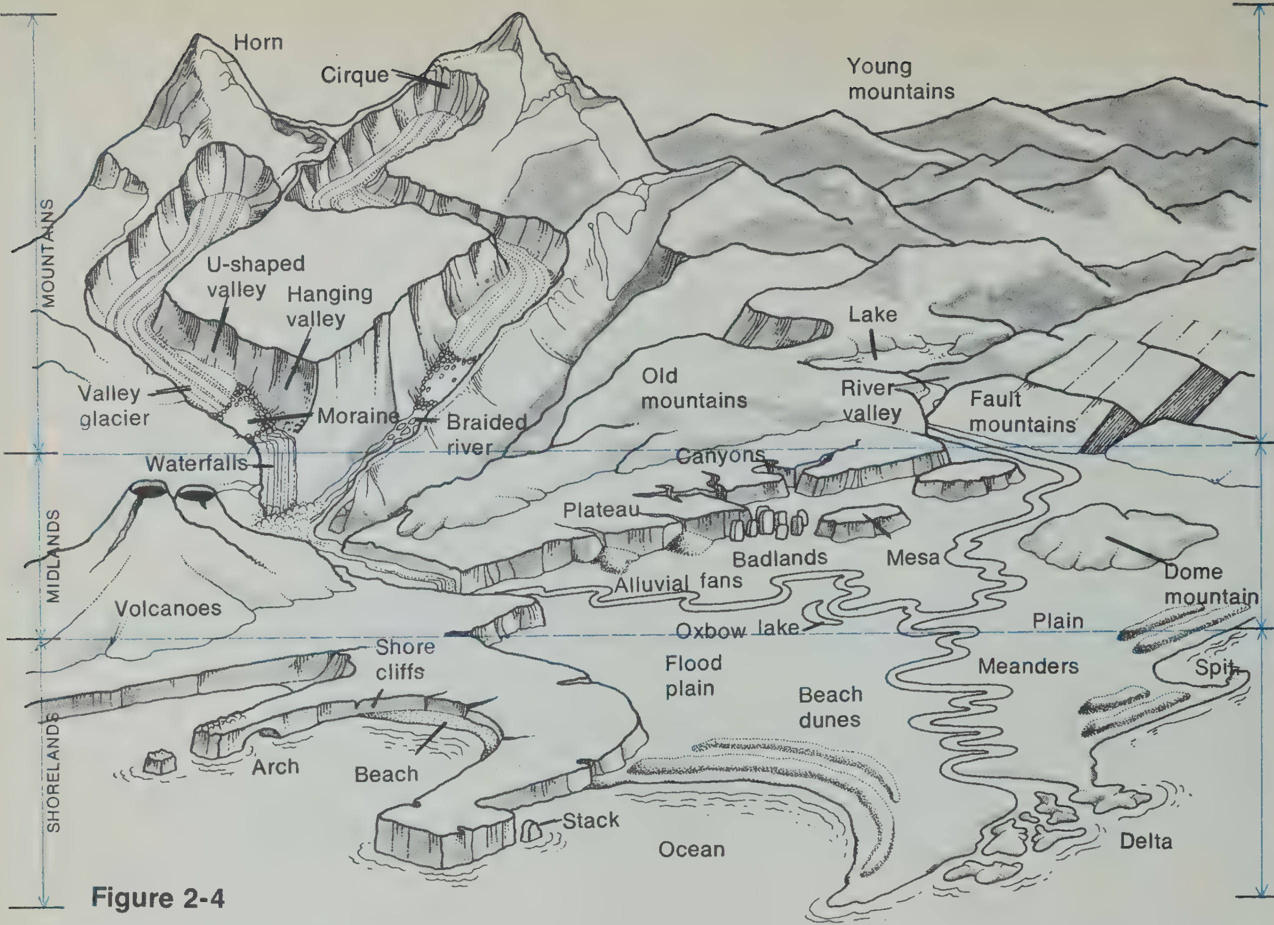


Figure 2-4

GET IT READY NOW FOR CHAPTERS 3, 4, 5

The next three chapters utilize a lot of equipment. Included in the list are the following items that must be procured locally: white paper, scissors, a needle or sharp nail, test-tube rack (may be homemade), piece of foil or glass, baby-food jars, knife, paper towels, stoppers for test tubes, white and colored chalk, teaspoon, paper cups, metal file, sandpaper, piece of masonite or plywood, bricks, matches, rulers, block of wood, pan of sand.

Students will use the numbered rock samples in Chapter 3 and the accompanying excursions. The numbered minerals are used in Excursion 3-1. Several of the excursions use rather extensive supplies that must be readily available. Be sure that all rock and mineral samples are numbered before being put out for student use. The HCl solution for use in Excursion 3-2 and 3-3 should be about 0.5M. To prepare it, add 20 ml of concentrated (12M) hydrochloric acid (HCl) to 480 ml of water. Dispense in dropping bottles labeled "Dilute HCl."

Part II centers upon some of the most spectacular scenery in the United States—the mountains. In this part of the module, you will try to figure out how landscapes like the one in Figure 2-5 got the way they are. You may even try to guess what the area will look like in the future.

Figure 2-5

Figure 2-6

Part III deals with what might be called the "midlands" of the United States. Among the features you will interpret are the ones shown in Figure 2-6.

Figure 2-7

Part IV deals with the area that borders the sea—the shorelands. Examples of the kind of features you will study in these chapters are shown in Figure 2-7.

When you have finished all the chapters and the appropriate excursions, you should be better able to interpret the country you live in. Good luck!

Before going on, do Self-Evaluation 2 in your Record Book.

These pages are designed to give students a look at the "coming attractions." Parts II, III, and IV cover three main topics—mountains, midlands, and shorelands. You can have the students do these in any order they wish. It is, in fact, advantageous to have different students working on different parts of the module. This will reduce bottlenecks in the use of specialized equipment such as the stream table.

EQUIPMENT

None

PURPOSE

To acquaint students with the concept of latitude and longitude and how they are measured.

MAJOR POINTS

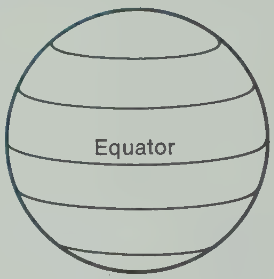
1. Latitude lines divide the earth into slices parallel to the equator.
2. Longitude lines go through the Poles and divide the earth into wedges, like an orange.
3. Any point on the earth can be described in terms of the two coordinates latitude and longitude.

Excursion 2-1
Latitude and Longitude

Ever since people first traveled the seas, they needed a way to describe where they were on the earth. This meant they would be able to find their way home. It also meant they could get to a new place. The ancient Greeks figured out a system of imaginary lines to divide the earth into sections. Today we use a similar system. We call the lines *latitude* and *longitude*.

You can think of latitude as dividing the earth into parallel slices. This is shown in Figure 1.

Figure 1

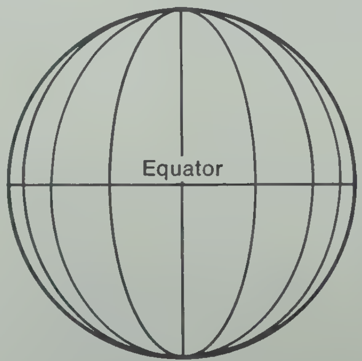


Lines of latitude

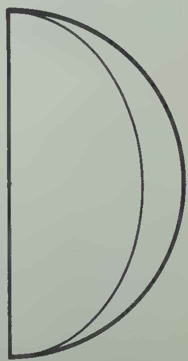
Latitude divides the earth into parallel slices.

Longitude lines go through the North and South Poles. They divide the earth into wedges, like an orange. You can think of longitude as dividing the earth into "long" slices.

Figure 2



Lines of longitude



Longitude divides the earth into wedges.

☐ **1.** In what two ways are longitude lines different from latitude lines?

☐ **2.** Which lines are parallel to each other?

In order to make latitude and longitude lines useful, they are given numbers. You can describe any point on the earth by using the latitude number and the longitude number for that point. Take New York City, for example.

☐ **3.** Using the numbers shown in Figure 3, what is the position of New York City?

a. Latitude (parallel) ______

b. Longitude (long slice) ______

☐ **4.** Latitude and longitude may be used on flat maps as well as globes. What would be the position of City Hall in New York City on the map in Figure 4?

a. Latitude ______

b. Longitude ______

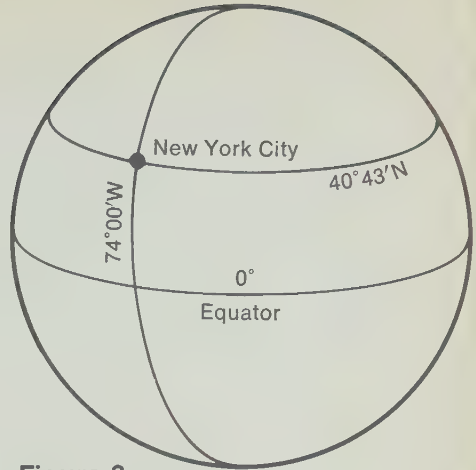
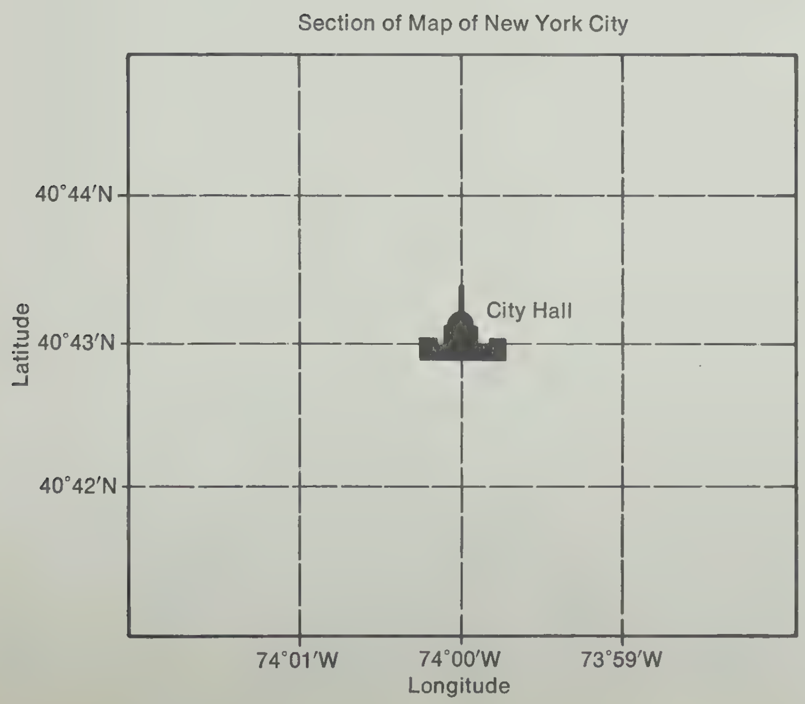


Figure 3

Figure 4



But what do the numbers mean? They are degrees (°) and minutes (′). These are actually angles measured from the center of the earth, as shown in Figure 5.

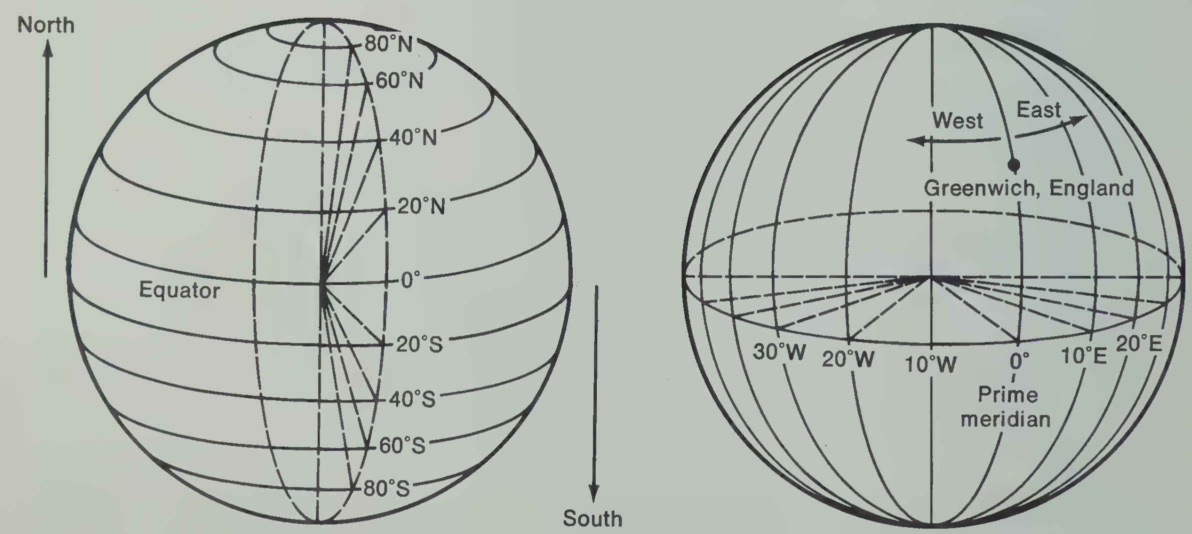
People have had to start measuring from somewhere! Latitude is measured north or south from the equator. Longitude is measured east or west from the "prime meridian." (This is the longitude line passing through Greenwich, England.)

☐ **5.** What is the latitude of the equator?

☐ **6.** What is the longitude of the prime meridian?

☐ **7.** Is the longitude of New York City (Figure 3) east, or west, of the prime meridian?

Figure 5



Latitude lines (or parallels)

Longitude lines (or meridians)

☐ **8.** Latitude lines are labelled either north or south. In relation to what line are they measured?

☐ **9.** Longitude lines are labelled either east or west. In relation to what line are they measured?

PART II

The Mountains

Excursions 3-1 through 3-4 are keyed to this chapter.

Mountain Materials 3

CHAPTER EMPHASIS

Mountains are spectacular geologic features that have been subjected to forces from within the earth. Making observations of both the materials and the general appearance of the mountains will enable the student to interpret how they were formed and to make predictions about their future.

FILMSTRIP KEY

Techniques
Classifying Rocks
Enrichment
Matter, Minerals, and Rocks
Weathering and Soils

EQUIPMENT

*Numbered rock samples
1 hand lens
1 needle or sharp nail
3 paper cups
Several teaspoons
Fine sand
Ferrous sulfate
Ferrous ammonium sulfate
Scissors
Paper towels
Burner fuel
3 test tubes
1 baby-food jar
1 alcohol burner
1 test-tube rack
3 small, disposable cups
1 flat metal or glass surface
Naphthalene flakes
Sodium thiosulfate
Sulfur
3 beakers or other containers
Safety goggles
Paper
1 test-tube clamp
Sharp knife

Suppose you were asked to guess where the photograph in Figure 3-1 was taken. We're not so interested in the place as in the general geologic setting of the picture. As a clue, we'll tell you that the features you see are called *ripple marks*.

Did you guess a seacoast, a stream, or a lakeshore? All of these are obviously sources of water. You may be surprised to discover that the ripple marks you see are in the Rocky Mountains in Colorado!

Figure 3-1

Not only are they in the Rocky Mountains, but they also are not lying flat. Look at the complete scene in Figure 3-2 on page 30. The ripple mark surface is tilted!

MAJOR POINTS

1. Interpretations of geologic phenomena such as tilted rocks with ripple marks can be made only after careful observations.
2. The observation of a rock's texture will enable the student to make inferences about its origin.
3. Rocks can be classified according to texture and the process of formation. There are three major classes of rocks: igneous, metamorphic, and sedimentary.
4. Most rocks are composed of only a few varieties of minerals. This study is limited to a few silicates, calcite, galena, and hematite.
5. A model for the formative processes of igneous, metamorphic, and sedimentary rocks can be made by simulating the process in the laboratory.
6. The rate of cooling of molten material has an effect on the texture of the solid that is formed.
7. When molten rock forces its way into cracks deep in the earth, it is called an intrusion.
8. When some substances are cooled very rapidly, crystals do not have time to form, and a glasslike texture results.
9. Conditions of weathering, heat, or pressure can change one type of rock into another type.

*The rock samples must be numbered before they are put out for student use. This can be done as described in the Introduction section of this Teacher's Edition. Note that although each bag of rocks comes labeled with a catalog number, the rocks are *not* referred to in the text by their catalog number. Instead, two-digit numbers have been assigned for the sake of simplicity. These are the numbers that should be marked on the rock samples.

Figure 3-2

We have two observations here, don't we? First, we observe a feature that was probably formed underwater, perhaps in the sea, but here it is high in the Rocky Mountains. Second, the surface upon which the ripples are seen is tilted.

Looking at the real thing or even a picture can tell you a lot about a mountain. But one small rock from it can tell you a lot more. This chapter is about the information individual rocks can give you. The next two chapters are about "the big picture."

Let's begin by examining materials taken from mountains. In the next four activities your goal will be to examine six rock samples and describe them in terms of their texture. You'll discover that you can tell a lot about a rock from its texture.

You will need a hand lens, a needle or nail, and the following samples from the rock kit: 05, 06, 08, 12, 13, 17.

There is purposely an element of discovery in the use of the specified equipment. The teasing needle, which can be an ordinary large needle or a sharp nail, is used as a fine pick to loosen individual grains of material from the rock sample. If these grains differ in color or other characteristics, it is reasonable to say that the sample consists of more than one kind of material.

ACTIVITY 3-1. Pick up a rock sample and look at it in good light with a hand lens. Hold the rock a few centimetres from your eye, with the hand lens up to your eye. Rotate the sample in your hand and closely examine the surfaces of the rock.

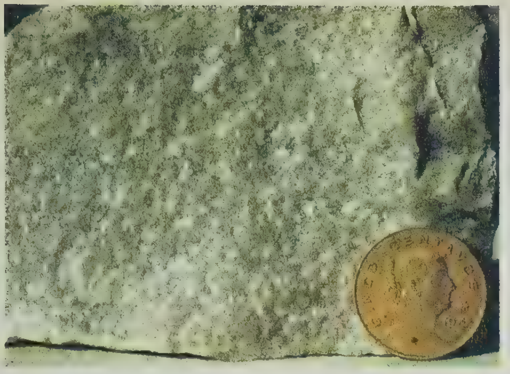
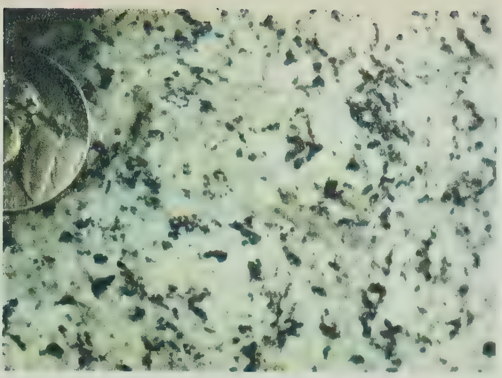
 

Figure 3-3

ACTIVITY 3-2. First decide whether the rock is made of only one kind of material or component, or more than one. (If grains of material differ in color or other characteristics, you can say there is more than one material in the rock sample.) Enter your decision in Table 3-1 in your Record Book.

☐ **3-1.** Which photograph in Figure 3-3 shows a rock that obviously has more than one material?

If a sample has two or more materials, there are two ways the materials may be held together. If the grains are closely fitted together like tiny pieces in a jigsaw puzzle, they are said to be *interlocking*. If the pieces are held in place by a natural cement, they are said to be *noninterlocking*.

ACTIVITY 3-3. Focus on the way the grains in the rock are held together. Decide whether they are interlocking, or noninterlocking. Enter your choice in Table 3-1. Do this for each rock sample.

At this point the students can only make a judgment on interlocking of components visually. Later they will study other factors that aid in making the decision.

Figure 3-4

☐ **3-2.** Which photograph in Figure 3-4 appears to have noninterlocking grains? Explain your choice.

Again, a decision on arrangement of components must be made visually at this point.

ACTIVITY 3-4. Take another look at the rocks you said have interlocking grains. Do the grains seem to line up in any special direction, or are they "randomly" arranged? For your answer, make a check in the appropriate column in Table 3-1.

Table 3-1

Sample Number	Number of Components	Texture		Arrangement	
		Interlocking	Noninterlocking	Random	Oriented
05					
06					
08					
12					
13					
17					

EXCURSION

You have found that several of the rock samples clearly were made of more than one material. Most of the materials are minerals. Although there are more than 2000 different minerals on the earth, only a dozen are needed to identify most rocks. **Excursion 3-1**, "Identifying Rock-forming Minerals," tells you how to identify the common minerals.

☐ **3-3.** True or false: A single piece of rock may contain more than one mineral.

Sort your rocks into two groups, one with interlocking textures and the other with noninterlocking textures.

Students who are careful observers will find the first four samples (gneiss, pink granite, gabbro, and marble) fall in the interlocking group; the other two samples (conglomerate and limestone) are noninterlocking in texture.

☐ **3-4.** Which samples are noninterlocking?

Scientists believe all rocks with noninterlocking grains were formed in the same way. They are made from particles, or sediments, that were deposited in the form of layers. But how do such sediments become hardened into rock?

The change into rock occurs in the presence of water. Since water contains dissolved minerals, you might expect these minerals to have some effect on the sediments. Try this experiment to find out. Note that you are asked to dissolve certain minerals in the water. This is to make sure that there will be enough minerals in the water. (The tap water in your school may not have enough dissolved minerals to make the experiment work.)

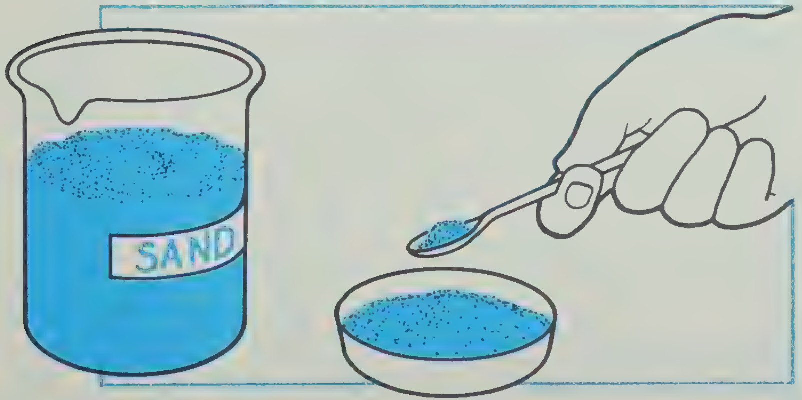
Go to the supply area and get the following items:

3 paper cups
1 teaspoon
Fine sand
$FeSO_4$ (ferrous sulfate), a soluble compound of iron
$Fe(NH_4)(SO_4)_2$ (ferrous ammonium sulfate), a soluble compound of iron
Scissors

Any flat dish can be used as long as it doesn't have a lip or ridges to prevent the hardened layer from being removed. For instance, a plastic petri dish works well, but because its diameter is about twice that of the paper cup, it will require about 4 times as much material (2 full teaspoons of chemical, more sand).

ACTIVITY 3-5. Cut a paper cup to make a small flat dish about 1 cm deep. Fill it about halfway with water and add about ¼ teaspoon ferrous sulfate. Shake the dish until the ferrous sulfate dissolves completely.

ACTIVITY 3-6. Now sprinkle fine sand into the water. Keep adding until wet sand almost fills the dish. Shake the dish to level the sediment. Set it aside in a warm safe place until your next class.



Repeat Activity 3-6, but this time use ferrous ammonium sulfate as the substance to be dissolved.

Also set up a third experiment, using only water and sand, without any dissolved mineral. Set these aside also.

When the sand has dried, it should drop out of the paper cup (or other container). Have students save the containers; they can be used by others in the same activities. Students should notice that the two containers that used dissolved chemicals hardened and turned yellowish in color. The cup containing only water and sand (the control) did not harden or change color.

☐ **3-5.** What is the purpose of this third experiment?

It will take at least a day for the sand to dry out. When it has completely dried out, remove it from the paper cup, and compare the results of the three experiments.

☐ **3-6.** What do you notice?

In this experiment, the presence of a dissolved iron compound in water causes a cementing and hardening action on the sand particles and turns them into a kind of rock.

Rocks such as you just made are called *sedimentary* rocks. They are made from sediments cemented together. Identifying them as sedimentary is easy. If they are noninterlocking, they are sedimentary. If they are interlocking, they are not sedimentary. And if you can't tell whether or not they are interlocking, well, then you have a problem.

Iron compounds have been identified as the cementing agent in many sedimentary rocks, and the yellowish or reddish color of many sandstones is due to the presence of such compounds in the cementing material.

EXCURSION

When you find an area that has sedimentary rock, you can usually see that the rock was formed in layers. Figure 3-5 is an example. **Excursion 3-2**, "The Formation of Layered Sediments," shows how such layered sediments form.

Figure 3-5

The formation of sedimentary rock begins close to the earth's surface, where sediments collect. Where do the sediments come from? Figure 3–5 shows surface sedimentary rock being worn away by a river. In this way, material from the rock becomes a source of new sediments. You can be quite sure that wherever this river sediment is collecting, more sedimentary rock may be in the making.

Not all rocks are formed from sediments. As you can imagine, there is a difference in rocks, depending on how they are formed. Some rocks are formed from the cooling of a very hot liquid that comes from deep in the earth. Such rocks are called *igneous* rocks. A third kind of rock is *metamorphic*. This kind is formed as a result of great pressure on igneous or sedimentary rocks deep in the earth.

☐ **3-7.** What kind of rock is volcanic rock?

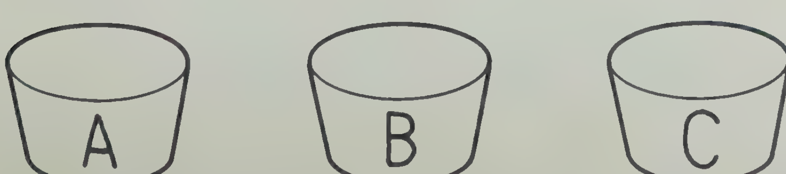
To be able to understand how igneous rock forms from molten rock, you can simulate (imitate) the process on a small scale. You will need the following items:

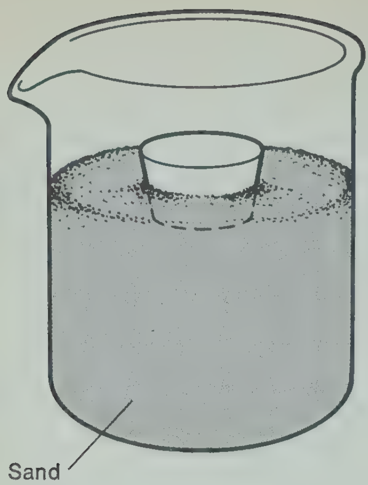
3 small spoons or scoops
1 test-tube rack
3 test tubes
1 alcohol burner
3 small sheets of paper
3 small, disposable cups
1 flat metal or glass surface (aluminum foil, window glass)
paper toweling
1 baby-food jar
3 beakers
Sand
Naphthalene flakes
Sodium thiosulfate
Sulfur
Safety goggles
1 test-tube clamp
Knife

If beakers are not available, deep pans or other firm-walled containers can be substituted.

Caution *This activity should be done in a well-ventilated room.*

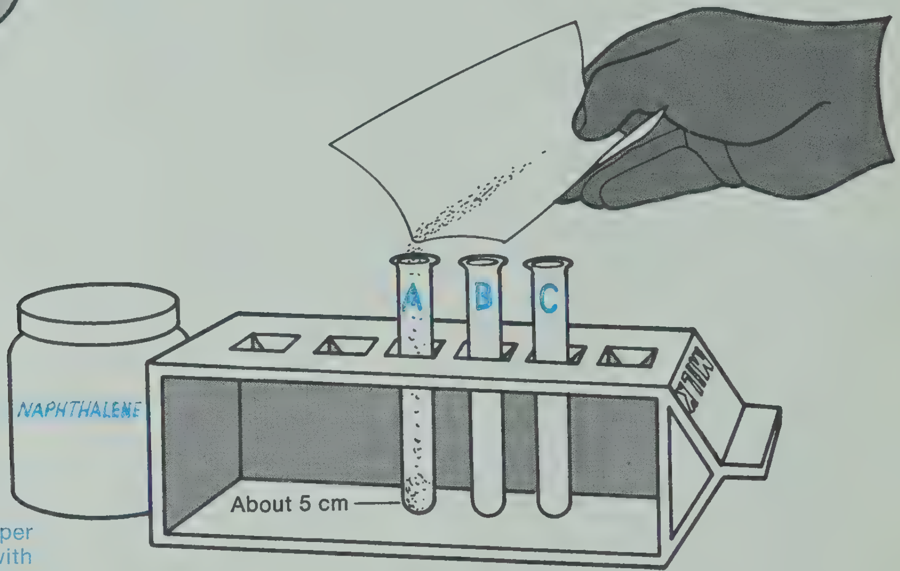
ACTIVITY 3-7. Label the three cups A, B, and C.





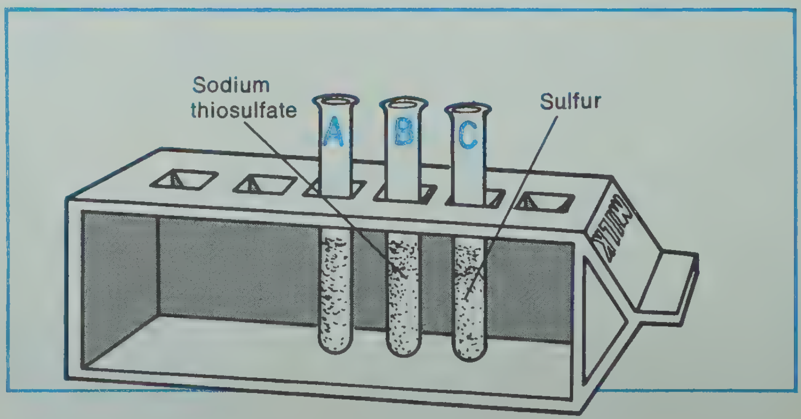
ACTIVITY 3-8. Fill a beaker about ¾ full of sand. Scoop out a small hole in the sand. Place cup A in the hole. Prepare two other beakers in the same way, using cups B and C.

ACTIVITY 3-9. Get 3 test tubes and label them A, B, and C. Put about 5 cm of naphthalene flakes into test tube A. (The easiest way to do this is to make a crease in a piece of paper. Then spoon some naphthalene flakes onto the paper. Pick up the paper, and let the naphthalene slide slowly down the crease into the test tube.)



Stress conservation of chemicals and proper techniques of handling and working with them. Avoid overheating any of the substances. Safety glasses should be used. The plugs of naphthalene (moth flakes), sodium thiosulfate (photographer's hypo), and sulfur may be reused after they have been inspected by the students. Break them up and reheat in the test tubes. It might be wise to have 3 baby-food jars, labeled "A-naphthalene," "B-sodium thiosulfate," and "C-sulfur," into which the students could put the used chemicals. Care should be taken to avoid mixing.

ACTIVITY 3-10. Put about the same amount (5 cm) of sodium thiosulfate into tube B and of sulfur into tube C.

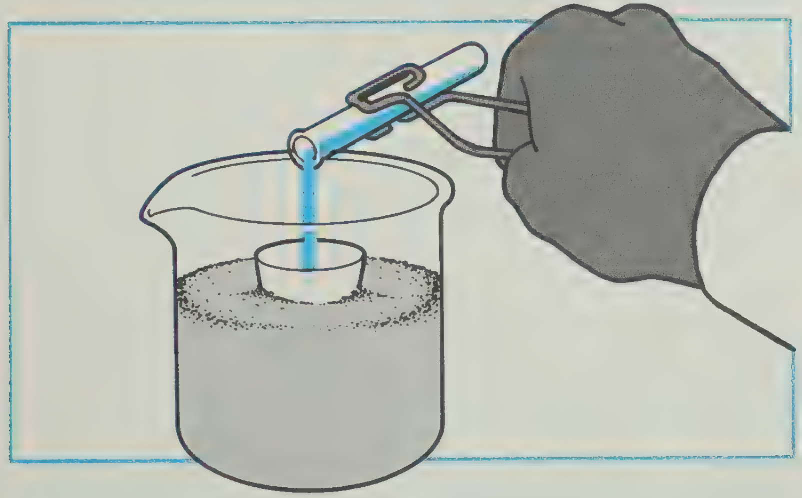


ACTIVITY 3-11. Very gently heat tube A until the naphthalene starts to melt. Then take the tube away and shake it gently. Heat a little more and then shake again. Keep doing this only until all the naphthalene has melted.

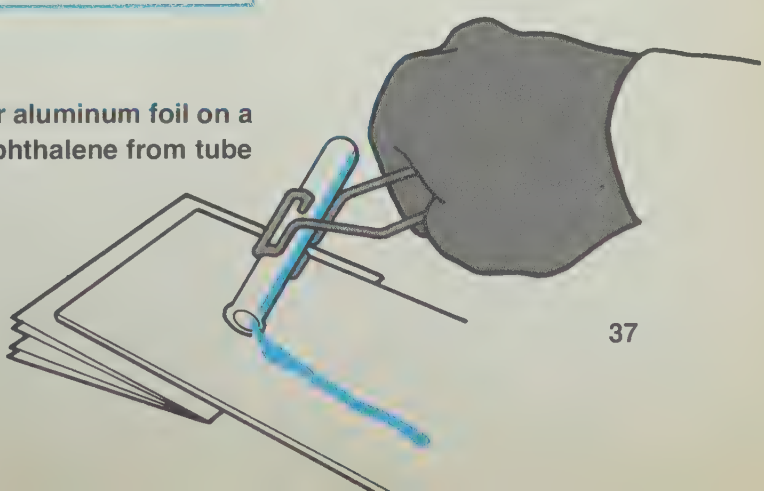
The naphthalene and sulfur fumes may get very strong, especially if the tubes are overheated. Thus it is important to plan for adequate ventilation in the room. (Have the students work near a fume hood if one is available.) Students should be reminded to stop heating the solids as soon as melting has been completed.

ACTIVITY 3-12. Pour part of the melted naphthalene quickly into the cup labeled A. Add just enough to fill the cup. Look at the top of the liquid every few minutes or so, but don't touch it.

5 cm of the powdered chemical may not be enough to fill the well when it is melted. More can be added after further melting without doing any harm.



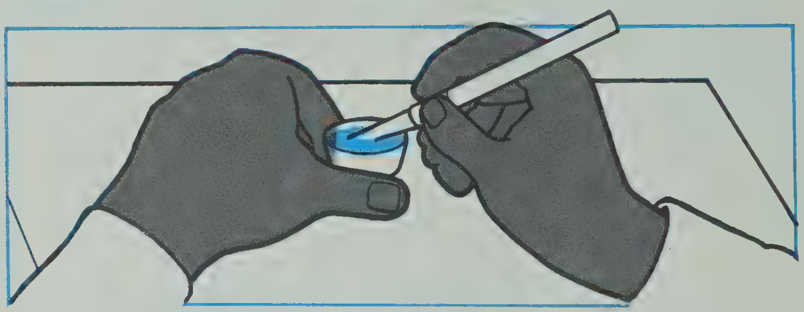
ACTIVITY 3-13. Prop the piece of glass or aluminum foil on a paper towel. Now pour the rest of the naphthalene from tube A down the gently sloping glass or foil.



Repeat Activities 3-11, 3-12, and 3-13, using the sodium thiosulfate and then the sulfur. Don't pour all the melted sulfur out of tube C. Set tube C aside after these activities. Meanwhile, keep checking on the melted materials you poured into the cups.

Now carefully compare the structure of the materials you poured onto the flat surfaces with the materials in the cups.

ACTIVITY 3-14. When the substance in each cup is completely solid, cut it in half with a sharp knife.



One of the difficulties with these activities is an adequate cleanup of the equipment and the area. Because both naphthalene and sulfur are insoluble in water, cleaning the test tubes may be troublesome. A little burner alcohol in the tube will help loosen these two materials.

☐ **3-8.** What differences do you observe between the substances cooled by pouring down the glass and the substances cooled by pouring them into a cup surrounded by sand?

Students should see that the crystals that formed by rapid cooling on the glass or foil are much smaller than those that formed inside the cup with slower cooling.

You have just carried out a *simulation* experiment. Pouring the molten (melted) material down a cold slope is somewhat similar to what happens when lava pours out onto the land surface. Lava, however, contains several different chemical substances, and it is much hotter. Its temperature is about 900–1100 °C. However, it cools fairly rapidly as it is exposed to the air.

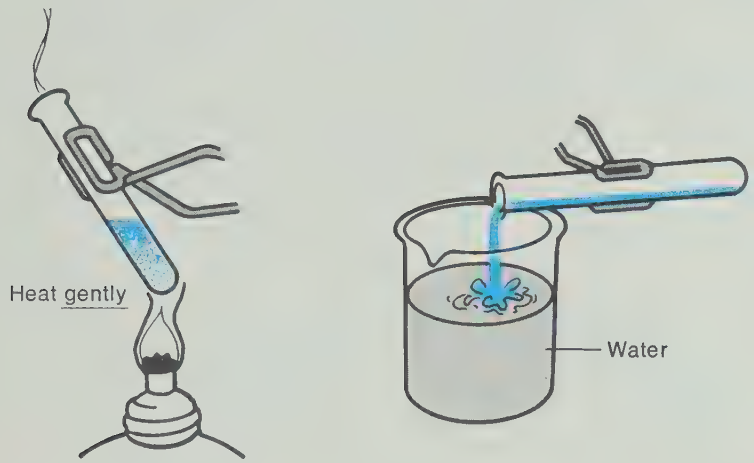
The liquid in the cup simulates molten rock that has formed deep in the crust of the earth. There the surrounding rock, like the sand, prevents rapid loss of heat. A body of igneous rock formed in this way is called an *intrusion*.

Sometimes the lava in contact with the cold rock at the edge of an intrusion is chilled more quickly than the lava in the center.

Look at the substances in the cups. Study the material in the very center (B in Figure 3-6). Study the material that was nearest the sand (A).

What differences can you see?

ACTIVITY 3-15. Now get test tube C with the leftover sulfur in it. (If you used all the sulfur, add about 1 cm more.) Heat very gently, as you did before, to produce a pale-golden liquid. Do not continue heating after the sulfur melts. Have a beaker of cold water ready. Pour the liquid sulfur into the water.



Pick the lumps of solid sulfur out of the water and look at them closely. Compare the structure with the sulfur from the "intrusion" and from the "flow." These differences are very similar to differences in lava rock. If lava pours out under the sea, it rolls into lumps with a glassy-looking surface. If it pours out onto the land in thin streams, it cools very rapidly and may form a glasslike substance. This is because the very rapid cooling does not allow crystals to form properly.

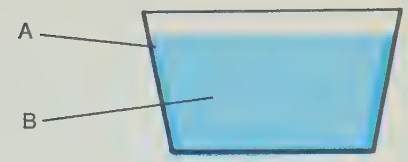
Look back at the six rocks you used in Activities 3-2, 3-3, and 3-4. Also look at the data in Table 3-1.

☐ **3-9.** Which rock samples appear to be igneous?

☐ **3-10.** What differences can you see in the crystals in the igneous rock samples?

☐ **3-11.** Can you predict which rock is from an intrusion?

Figure 3-6



Sulfur melts at a temperature of 114.5 °C, forming a pale-yellow, free-flowing liquid. If heating is continued, it becomes thicker and more viscous and is poured from the test tube with difficulty. It changes color to reddish-brown and then almost to black as temperature increases. An entirely different structure will result if the darker-colored sulfur is suddenly cooled.

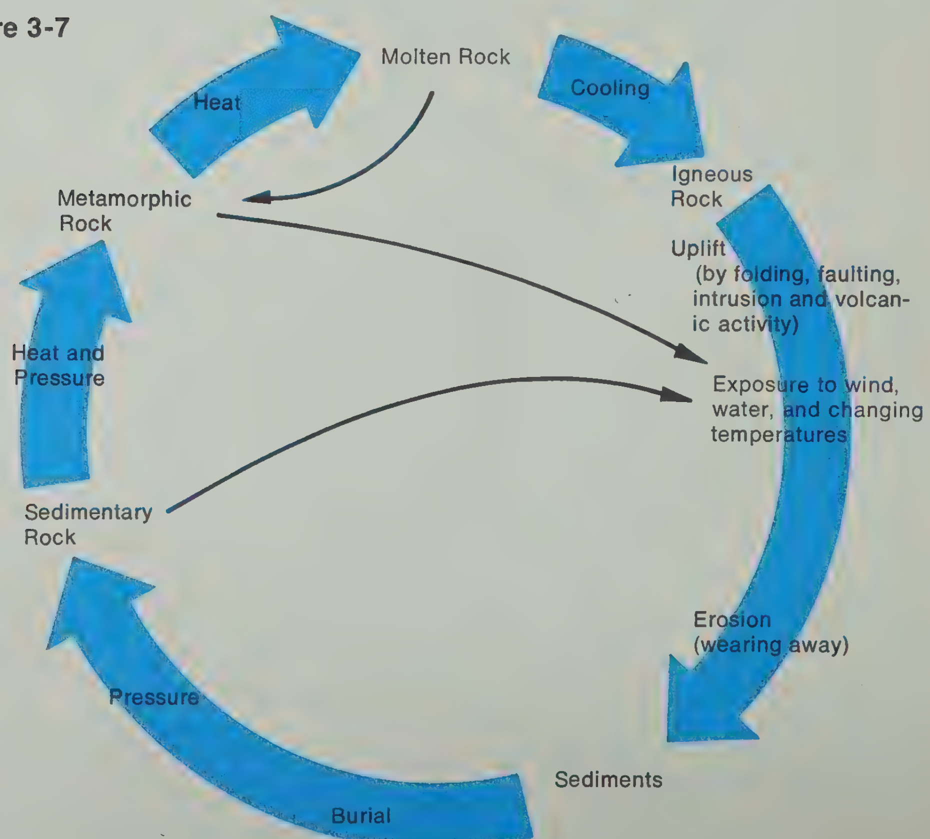
A simulation experiment is a useful device for developing a model of a process that is difficult to observe. And because there are active volcanoes in existence, geologists in the field can add some other evidence. Freshly cooled lava flows from a new eruption can be examined and compared with much older rocks.

In addition, there are simple chemical tests that can help you distinguish between different types of rocks. These tests also help you identify what the rocks are made of. If you're interested in learning more about how to identify rocks, try **Excursion 3-3**, "Classifying Rocks." You can use this to check your observations in Table 3-1.

EXCURSION

The earth's crust is in constant change. Whether you examine rock in the mountains, the midlands, or the shorelands, you see the same cycle of change. Figure 3-7 is a simplified diagram of the rock cycle. With it, you should be able to predict how one kind of rock can change into another kind.

Figure 3-7



As a starting point, look at the top of the circle. Molten rock, or lava, is cooled on contact with the air and becomes a hard igneous rock. When pushed upward to the surface, this rock is exposed to weathering. Like any rock exposed to wind, water, and changing temperature, it is broken down into smaller and smaller particles. These become sediments, which are carried away toward the ocean. There they pile up. New sediments bury the first ones.

In time, the buried sediments become hardened to form sedimentary rock. With added pressure and heat, the sedimentary rock may change to metamorphic rock. The metamorphic rock can melt and become igneous rock once again. This completes one round of the cycle.

☐ **3-12.** Look back again at the eroding rock in Figure 3-5. Where in the rock cycle does this picture fit?

☐ **3-13.** From where to where would an arrow have to be drawn in Figure 3-7 to show what the river is doing to the rock?

The next chapter takes you on a tour of the mountains of the United States. Before starting, let's get a general picture of the distribution of rocks in the country and how they are associated with the mountains. Examine the map in Figure 3-8. This shows the distribution of flat-lying sedimentary, steeply-tilted sedimentary, and igneous and metamorphic rocks. Compare the rock distribution map with the map showing the location of the mountains in the United States (Figure 3-9). Using these two maps, answer the following questions.

Figure 3-8

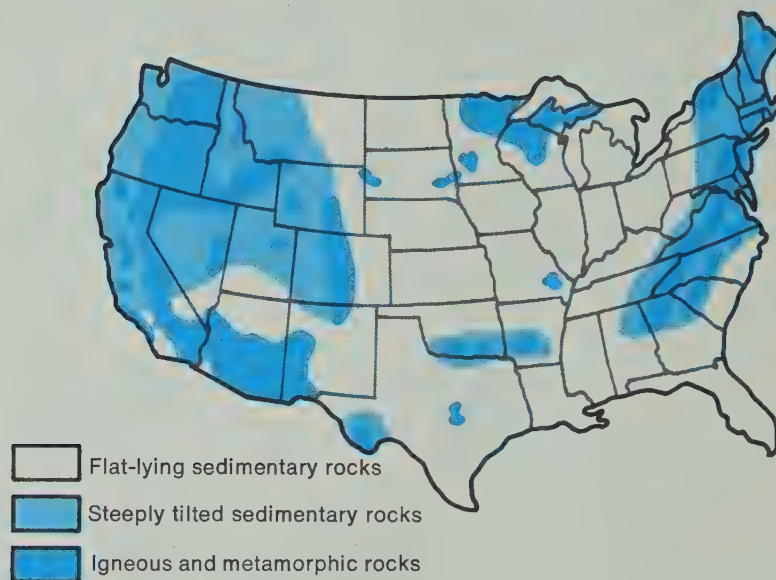


Figure 3-9

Mountains of the United States

☐ **3-14.** What kind of rocks would you find if you visited the Appalachian Mountains?

☐ **3-15.** Are there any mountains in your state? (If not, go on to question 3-16.) What is the name of these mountains? What kind of rocks are found in them?

☐ **3-16.** If your response to 3-15 was No, where are the closest mountains?

☐ **3-17.** What kinds of rocks would you find there?

Excursion 3-4 shows you how you can find all three types of rock in a fairly small region—a field trip in your own classroom!

Before going on, do Self-Evaluation 3 in your Record Book.

3-14. Possibly all three kinds. The uplifted rocks were originally sedimentary, but some may have been metamorphosed. Intrusions of granite and other plutonics occur along the Blue Ridge. The valley and ridge provinces consist entirely of sedimentary rock.

EXCURSION

Excursion 3-1
Identifying Rock-forming Minerals

EQUIPMENT
Glass plate
Knife
Hand lens
Mineral kit
(13 samples—see Introduction section of this Teacher's Edition.)

PURPOSE
To show a simplified classification system for identifying minerals.

Encourage students to work together as they peel off a layer of biotite mica and, also, to peel off a minimum layer. The samples can become quickly fragmented otherwise.

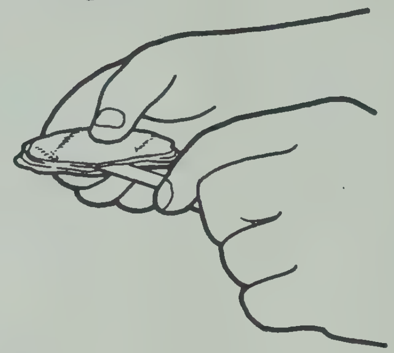
MAJOR POINTS

1. The more than 2000 minerals can be reduced to about 12 important ones that are useful in the study of rocks.
2. Cleavage faces will flash when rotated in a bright light.
3. Mineral hardness can be classified as harder or softer than glass.
4. Minerals can be classified as having either metallic or nonmetallic luster.

Of the more than 2000 different minerals on the earth, about a dozen are useful in the study of rocks. This excursion shows you a simplified classification system to help you identify common mineral specimens.

Obtain from the supply area a kit of minerals with 13 samples, a glass plate, a knife, and a hand lens.

ACTIVITY 1. Pick up mineral sample 29 (biotite mica) and carefully try to peel a layer off the top. Place a knife between the layers and lift. This peeling or separation along a smooth surface is called cleavage.

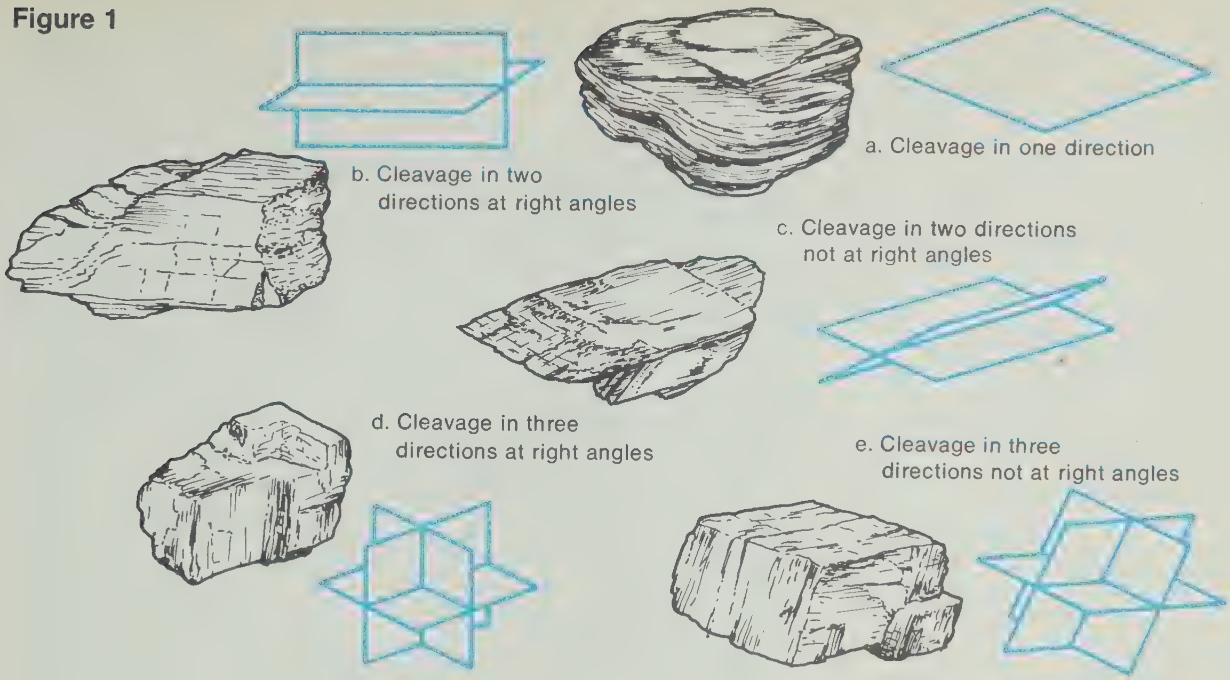


ACTIVITY 2. Hold the sample in your hand with the fresh surface up at about eye level. Now rotate the sample until you see a flash of light. Cleavage surfaces will flash in light as a mirror will if you hold it at the right angle to the sun.

Minerals can have several cleavage surfaces. The mineral you are now holding has one cleavage surface.

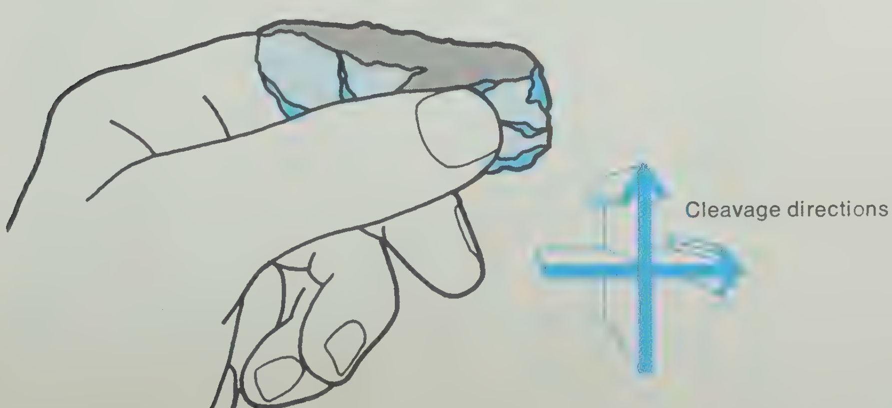
Examine the drawings in Figure 1. Cleavage surfaces are shown for samples having one, two, and three directions.

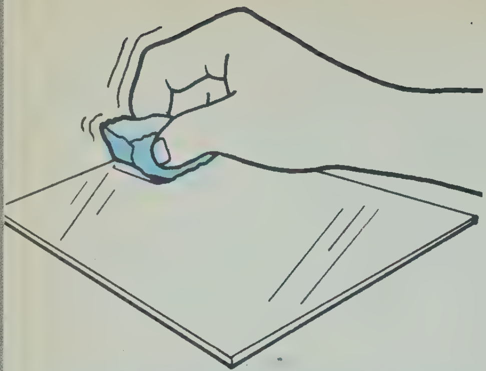
Figure 1



Remember that cleavage faces will flash when you rotate them in good light; other surfaces will not.

ACTIVITY 3. Pick up mineral sample 23 (microcline feldspar). Hold the sample in good light and rotate, looking for flashes. You should be able to identify two cleavage directions, at about 90° to each other.





The glass plate called for here can be salvaged scraps of window glass. Your custodian may have some that he would be willing to give you and even trim up with a glass cutter. Local glass companies also have scraps that they will give away. Warn students about handling the sharp edges. It may be advisable to put masking tape around the edges as a safety measure.

ACTIVITY 4. Lay the glass plate on the table. Holding mineral sample 23 (feldspar) in your hand, try to scratch the glass with the sample. To determine if you have scratched the glass, rub your moistened finger across the mark. If the mark comes off, then you have not scratched the glass. If the mark remains, look closely at it with a hand lens.

If you can scratch the glass with the mineral, then we conclude that the mineral is harder than glass. If you cannot scratch the glass, then the mineral is softer than glass.

☐ **1.** Is mineral sample 23 harder, or softer, than glass?

You should have determined that mineral sample 23 is harder than glass.

Using the same mineral you tested in Activity 4, determine its luster. To do this, examine Figure 2, which shows two photographs of minerals. The one on the left has a metallic luster (looks like a metal). The other has a nonmetallic luster (looks glassy, greasy, waxy, pearly).

☐ **2.** What kind of luster does mineral sample 23 have?

Figure 2

The mineral in the lefthand photo is hematite. The one on the right is muscovite mica.

To identify a mineral, you will need to determine its luster (metallic or nonmetallic), its hardness (harder or softer than glass), and if it has cleavage surfaces. When you determine these three properties, you should then refer to the Mineral Classification Chart.

Identify each of the samples in the mineral kit by following the procedure just described. Record your results in your Record Book.

Mineral Classification Chart

Luster	Hardness	Cleavage	Special Properties	Name
Nonmetallic luster	Harder than glass	Cleavage	2 directions of cleavage; pink, white	Microcline feldspar
			2 directions of cleavage; white, blue-gray, striations (lines) on some cleavage planes	Plagioclase feldspar
		No cleavage	Red, brown, or yellowish-green	Garnet
			Olivine green; commonly in small glassy grains	Olivine
			Transparent, milky-white	Quartz
	Softer than glass	Cleavage	Brown to black; perfect cleavage producing thin elastic sheets	Biotite mica
			3 cleavage directions—surfaces look like this ▱; colorless, white; effervesces in HCl	Calcite
			Clear gray, perfect cleavage, producing thin elastic sheets	Muscovite mica
			Dark-green to black; 2 cleavage directions	Hornblende and Augite
Metallic luster	Harder than glass	Cleavage	Brass-yellow color; cubes	Pyrite
		No cleavage	Red	Hematite
	Softer than glass	Cleavage	Heavy; silver-gray color; little cubes	Galena

Students may be interested to know that rock samples brought back from the moon contained a number of the minerals listed here. For instance, the glassy olivine was found in much of the dust and rock.

The cleavage in pyrite may be difficult to identify.

Hematite has a range of hardness. Some types of hematite are softer than glass.

PURPOSE
To examine some ways that layered sediments could form.

Excursion 3-2
The Formation of Layered Sediments

Because of the commonness of sedimentary rock, you may want to encourage students to bring in samples to "localize" the unit.

Rock outcrops can be found in mountains, plains, and seashore areas. Figures 1, 2, and 3 all show outcrops that have one striking feature in common. See if you can identify the feature that is similar in all three photographs. It is a feature that probably came about in roughly the same way in each case.

☐ **1.** What common feature do the three photographs have?

Figure 1

Figure 2

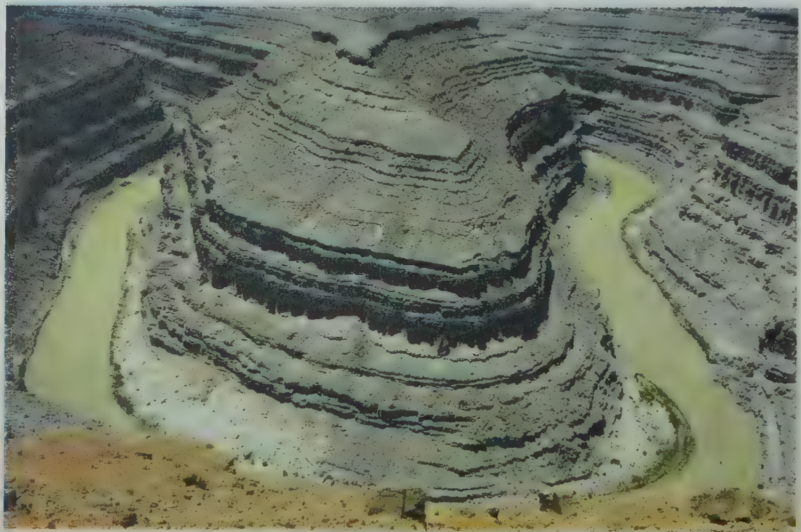


Figure 3

EQUIPMENT

1 tsp sand-silt mixture
1 plastic teaspoon
½ tsp calcium chloride
½ tsp sodium carbonate
2 baby-food jars
1 drop HCl (0.5M)
1 piece of glass
1 filter-paper disk
Rock kit (16 samples)
½ tsp crushed white chalk
½ tsp crushed colored chalk
½ tsp sand
½ tsp silt
Hand lens
4 test tubes
4 stoppers
2 droppers

MAJOR POINTS

1. The settling of different kinds of particles at different times could form layered sediments.
2. Chemicals can react to form a layer that behaves like limestone.
3. Particles of different sizes settle at different speeds.
4. Sandstone is composed of sand grains cemented together.
5. Shale is hardened clay or mud that often has a muddy odor when moistened.
6. Limestone is hardened calcium carbonate and reacts vigorously with HCl.

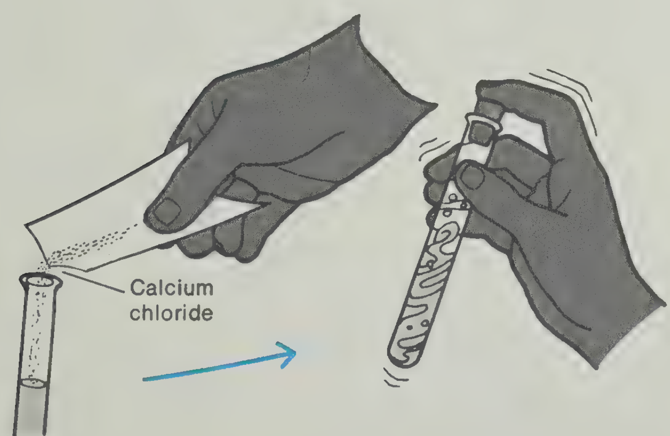
You can do some simple experiments to get some clues about the formation of this feature. You and a partner will need the following materials:

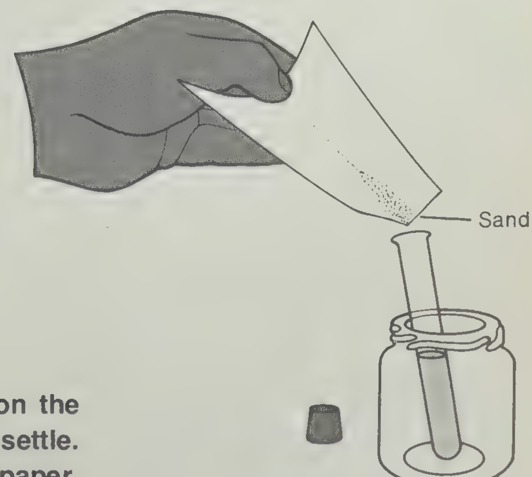
- 4 test tubes, with stoppers
- 2 baby-food jars
- Spoon
- 50 ml water
- ½ tsp crushed chalk (white)
- ½ tsp crushed chalk (colored)
- ½ tsp sand
- ½ tsp silt
- 1 tsp sand-silt mixture
- Small piece of paper
- 1 bottle of calcium chloride powder
- 1 bottle of sodium carbonate powder
- 2 droppers
- Dropping bottle of hydrochloric acid (HCl)
- 1 watch glass or other piece of glass
- 1 filter–paper disk

The white and colored crushed chalk, the sand, the silt, and the sand-silt mixture could be put on the supply table in 5 labeled baby-food jars. Students could then take the required amounts (½ teaspoon, 1 teaspoon) to their tables on small pieces of paper. It would help to have a different spoon with each substance. If this is not possible, the spoon should be cleaned.

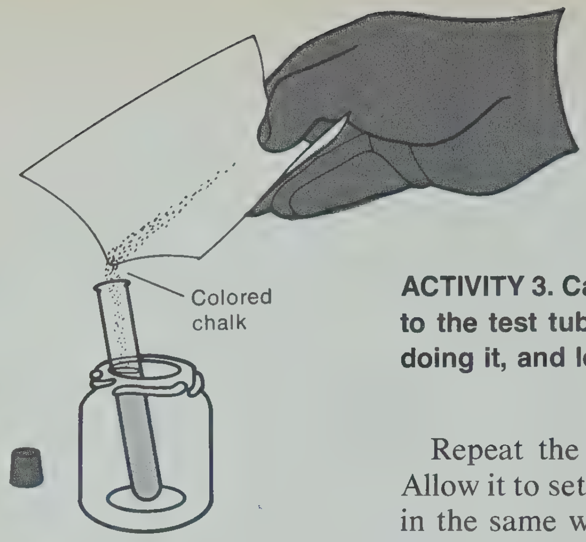
ACTIVITY 1. Fill a test tube about half full of water. Add about ¼ teaspoon calcium chloride. Cap the test tube and shake it to dissolve the calcium chloride.

Although students may use a spoon to transfer materials to the test tubes, the creased-paper technique has been suggested because it is easier and there is usually less spillage.





ACTIVITY 2. Stand the test tube in a baby-food jar on the table. Remove the stopper and let the water in the tube settle. Now put ½ teaspoon of sand onto a creased sheet of paper. Let the sand grains slide slowly down the crease and into the test tube.



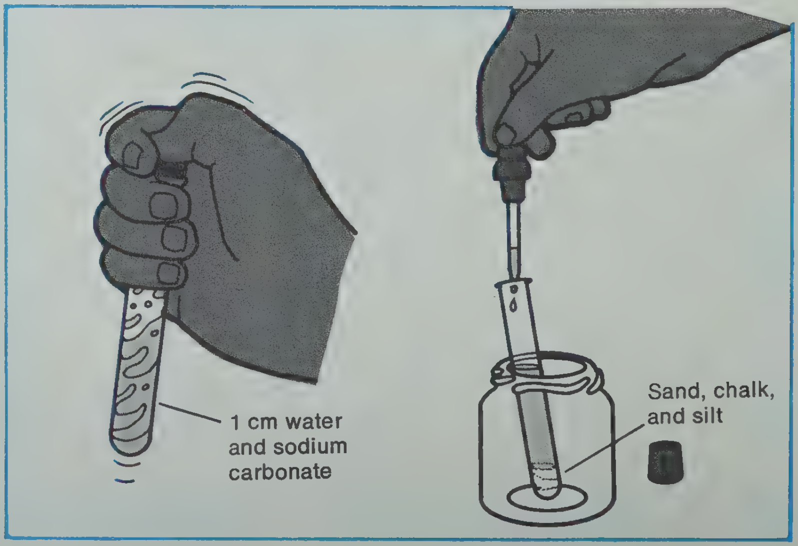
ACTIVITY 3. Carefully add ½ teaspoon crushed colored chalk to the test tube. Do not disturb the test tube while you are doing it, and let it stand for a few minutes afterward.

Repeat the process once more, using the white chalk. Allow it to settle for about two minutes and then add the silt in the same way. Now look into the test tube through the side, without disturbing it.

☐ **2.** Describe what you see in that test tube.

Sodium carbonate is washing soda. A small amount of the solution makes an excellent cleaning agent for the test tubes and other glassware at the conclusion of the activities.

ACTIVITY 4. Put about 2 cm of water into a clean test tube, and add ¼ teaspoon sodium carbonate. Stopper and shake it until everything dissolves. Take up the solution into a dropper. Slowly add the solution, a couple of drops at a time, into the test tube to which you added sand, chalk, and silt. Observe what is happening. When you have used all the sodium carbonate solution, let the test tube stand for several minutes.

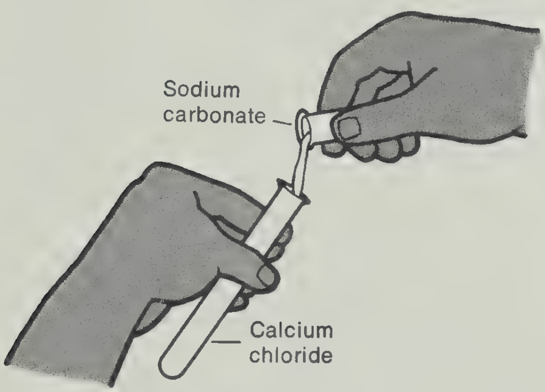


☐ **3.** How could this process of particles settling in water explain layers like those in the photographs on page 48?

☐ **4.** What evidence would you need about the rocks in the photographs to confirm that this process caused the layers to form?

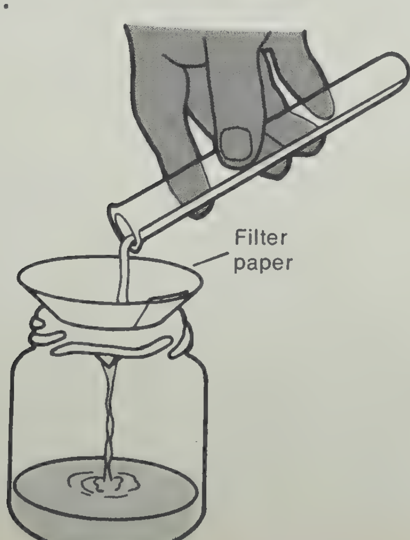
In the experiment just completed, you selected different kinds of particles, and you used a chemical reaction to produce another kind of particle. Let's take a closer look at the chemically formed particles.

ACTIVITY 5. Put about 1 cm of water into a third clean test tube. Add about ¼ teaspoon calcium chloride. Stopper the tube and shake it until everything dissolves. Make up a solution of sodium carbonate as you did for Activity 4. Add this solution to the calcium chloride solution.



ACTIVITY 6. Now filter the mixture you have made into a baby-food jar.

If filter paper is available, fine. A paper towel, cut in a 10-cm circle and folded so that it forms a cone, will also work satisfactorily.

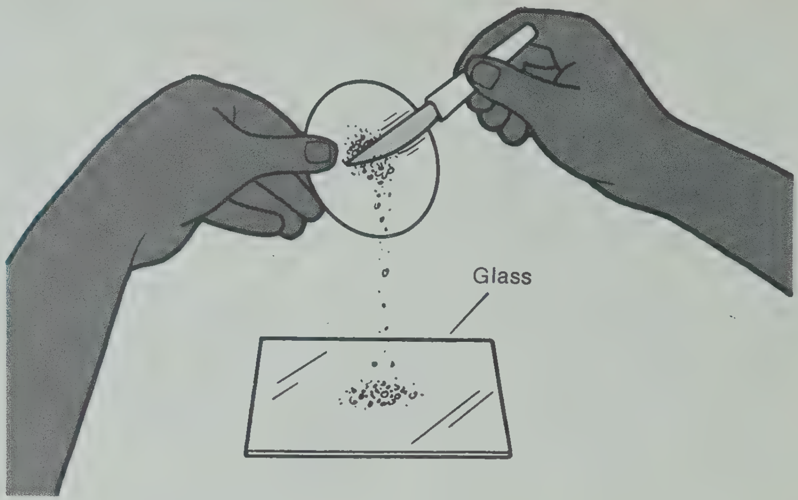


The residue, for your information, is the product of the chemical reaction between calcium chloride and sodium carbonate:

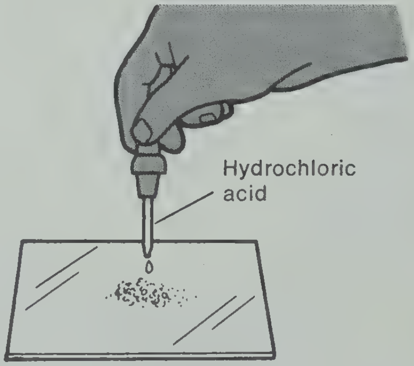
$$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3\downarrow + 2NaCl$$

As you can see, the liquid that passed through the paper contained salt.

ACTIVITY 7. Scrape the particles off the filter paper onto a small watch glass or other piece of glass. The particles on the glass are the residue.



ACTIVITY 8. Using a clean dropper, add one drop of hydrochloric acid to the residue.



Caution *Be careful not to spill the hydrochloric acid. Wash your hands, the tabletop, and the test tube after working with the acid.*

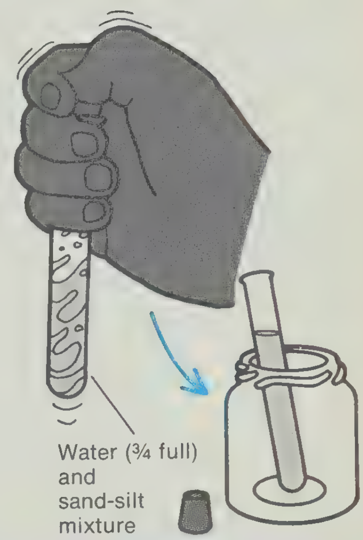
☐ **5.** What happened when you added hydrochloric acid to the particles?

You will find that some of the rock specimens in the rock kit will react in a similar way with hydrochloric acid. These rocks are called *limestones*. They contain calcium carbonate, the same chemical contained in the particles that settled out of the solution in Activity 4. Some limestones are thought to have been formed by the settling-out of calcium carbonate in layers.

Sandstone, as its name implies, is composed of sand grains cemented together. *Shale* is hardened clay or mud. It often has a "muddy" odor when it is moistened. Though both are sedimentary rocks, neither actively fizzes with HCl.

☐ **6.** How can you tell limestone, sandstone, and shale apart?

ACTIVITY 9. Take your fourth clean test tube and fill it about three-fourths full of water. Pour about 1 teaspoon of the sand-silt mixture into the test tube. Stopper the test tube and shake it vigorously for a few seconds. Put the test tube into the jar and let the contents settle. Carefully observe what is happening.



The grains in shale should be the smallest, having formed from mud or clay. Sandstone should show larger, angular grains of sand. Limestone should show globular clusters of white calcium carbonate, larger grained than either of the others. Limestone also reacts actively with HCl.

☐ **7.** What do you notice about the rate of settling of the different-sized particles?

These simple experiments and the evidence in the rock specimens give a few clues that layers might be formed by particles settling out from water. But how are these layers changed into rock?

After careful thought and experimentation, geologists have concluded that sedimentary rocks like sandstone, shale, and limestone were formed in lakes and seas. The theory is that the sand and clay particles that were deposited in seas and lakes became cemented into sandstone and shale. Limestone is thought to come from calcium carbonate that was once dissolved in seawater (calcium carbonate is part of the "salt" of the seas).

Excursion 3-3
Classifying Rocks

PURPOSE
To provide a step-by-step series of tests for rock classification.

The properties of a rock are a result of how the rock was formed. Thus, in this excursion you will make careful observations of rocks in order to determine how they were formed. In doing this, you will then be able to tell if a given rock is sedimentary, igneous, or metamorphic.

Go to the supply area and pick up a kit of mixed rocks, a hand lens, 1 bottle of HCl, and a steel nail. Before working through the activities that follow, predict which rocks in the kit you believe were (1) once molten and then hardened as they cooled, or (2) once sediment but then cemented together. Record your predictions by checking one column of Table 1 in your Record Book. At the end of the excursion you can check to see how good your predictions were.

Table 1

Rock sample	Predicted origin	
	Molten/hardened	Sediment/cemented
05 (gneiss)		
06 (pink granite)		
07 (gray granite)		
08 (gabbro)		
09 (basalt)		
10 (rhyolite)		
11 (obsidian)		
12 (marble)		
13 (conglomerate)		
14 (pumice)		
15 (quartzite)		
16 (shale)		
17 (limestone)		
18 (slate)		
19 (sandstone)		
20 (schist)		

EQUIPMENT

1 rock kit (16 samples—see Introduction section of this Teacher's Edition.)
1 dropper bottle of HCl (0.5M)
1 nail or needle
1 hand lens

MAJOR POINTS

1. Rocks may be classified by using tests for texture, composition, fossils, and reaction to chemicals.
2. A Yes-No series of questions can be asked about rock samples that will lead to a decision.

It is not essential that students test all 16 samples. An adequate idea of how rocks are categorized can be gained from, say, half a dozen specimens. If fewer than the total number of samples are used, make sure that each student team has a sampling of sedimentary, metamorphic, and igneous rock.

Listed below are a few simple tests that will help you sort the rocks. Read the tests first so that you understand them. Then classify the rocks as to whether they are igneous, metamorphic, or sedimentary. To do this, use the tests and the sequence of numbered questions that follow. Record your findings with each test in Table 2 in your Record Book.

ROCK TESTS

ACTIVITY 1. *Texture Test:* Determine whether the specimen (1) has visible components (minerals) that are held together in an interlocking fashion, (2) has visible components (minerals) that are held together by a cement (noninterlocking), (3) looks glassy and is very smooth, (4) looks frothy and has lots of holes in it, or (5) has a very fine-grained appearance and seems to lack minerals.

☐ **1.** Study each of the five items in the Texture Test. What kind of rocks would each item apply to?

ACTIVITY 2. *Composition Test:* Look at the minerals in the specimen and try to identify as many minerals as you can. The minerals you are most likely to see are quartz, feldspar, mica, calcite, and hornblende. If you cannot identify these, do Excursion 3-1, "Identifying Rock-forming Minerals."

Note the reference to Excursion 3-1 titled "Identifying Rock-forming Minerals." This excursion uses the kit containing 13 minerals, and other equipment. Caution students about getting the rocks and minerals correctly separated after they are through using them, and in getting the other materials back to supply, before going on.

ACTIVITY 3. *Fossil Test:* Look for fossils in the rock. They may be in the form of small shells or imprints of leaves.

☐ **2.** What does the presence of fossils tell you about the history of a rock?

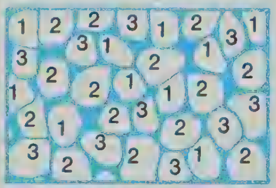
ACTIVITY 4. *Chemical Test:* Put a couple of drops of HCl on the specimen and look for bubbling.

You should caution students about using reasonable care in handling the acid. Although dilute, it is corrosive and can damage clothing and other materials. Rocks (and hands) should be washed upon completion of the test. Note that if bubbling occurs, the rock cannot be igneous.

Caution *Be careful not to spill the hydrochloric acid. Wash your hands, the tabletop, and the rock specimen when you are done.*

You will not have to do all four activities for each rock sample. Begin by picking up a specimen and writing down

The description in statement 3 does not apply to all metamorphic rocks. Other properties of metamorphic rock are described in statements 6 and 14. In fact, it is rather difficult to make generalizations about any of the three main types of rock. Therefore, the asterisked statements are not intended to apply to all specimens within a category of rock. Each statement merely describes one of several possible identifying characteristics.



Students are sometimes reluctant to use the step-by-step method and may tend to accept what another student has found. Encourage them to develop the technique for themselves.

its number. Ask yourself the following questions. As you answer each one, put a check in the appropriate box in Table 2 in your Record Book. If you reach a statement with an asterisk, then you can make a decision on the specimen at that point. You won't need to go any further in checking that specimen. When that happens, pick up another specimen and start with question 1 again.

1. Is the rock made up of visible minerals that are interlocking? If the answer is Yes, it cannot be sedimentary; go to 2 below. If the answer is No, go to item 7.

2. Do the interlocking crystals all seem to be the same mineral? If Yes, go to 3. If No, go to 4.

***3.** A rock with interlocking crystals of only one mineral is usually a kind of metamorphic rock.

4. Are the different minerals evenly distributed in the rock, as shown in Figure 1? (Each number in this drawing represents a different mineral.) If the answer is Yes, go to 5. If No, go to 6.

***5.** A rock with different types of interlocking crystals, evenly mixed together, is an igneous rock.

***6.** A rock with different types of minerals arranged in stripes or bands is a metamorphic rock.

7. Is the rock frothy (full of small holes)? If the answer is Yes, go to 8. If No, go to 9.

***8.** A rock with lots of small holes, that looks as though it has been full of gas at some time, is an igneous rock formed by cooling a gassy lava.

9. Is the rock glassy like a piece of colored broken glass? If the answer is Yes, go to 10. If No, go to 11.

***10.** A dark, hard rock that looks like glass is probably igneous rock formed by fast cooling of a lava flow from a volcano.

Table 2

Rock sample (no.)	**1.** Interlocking minerals?		**2.** Same mineral?		**4.** Evenly distributed?		**7.** Frothy (with holes)?		**9.** Glassy?		**11.** Visible particles?		**13.** Slatelike sheets?	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No

11. Does the rock contain easily recognized particles, like fine silt, sand, or pebbles, cemented together? If the answer is Yes, go to 12. If No, go to 13.

***12.** A rock made of silt, sand, or pebbles cemented together is sedimentary. It may have fossils. You can probably see the layering in good specimens.

13. Is the rock made up of strong, flat sheets that look as though they will split off into slatelike pieces? If the answer is Yes, go to 14. If No, go to 15.

*14. A nonsedimentary rock that splits easily into thin, flat sheets is probably metamorphic. The splitting has been caused by pressure. The rock was once sedimentary. If fossils are present, they are probably squashed and very distorted.

15. If you have come this far, you have a specimen that is difficult to identify. You may want to go through the questions one more time. Most likely, you will need an expert to help you sort this one out.

Table 3

Test	Sedimentary	Igneous	Metamorphic
Texture	Noninterlocking; size of minerals ranges from very large grains to invisible.	Generally interlocking; random distribution; size of minerals ranges from glassy to large grains.	Generally interlocking; random and oriented distribution in bands or flakes; size ranges from invisible grains to very large grains.
Composition	Minerals may include quartz, feldspar, calcite.	Usually contains quartz, feldspar, mica; sometimes hornblende, olivine.	Minerals may be quartz, feldspar, mica; some contain garnet or calcite.
Fossil	May have fossils.	No fossils	If fossils are present, they are usually squashed or twisted.
Chemical	May bubble with HCl.	Does not react with HCl.	May bubble with HCl.

Check your results with the summary in Table 3. If your classification of rock samples does not agree with the table, check with your teacher.

Also check the predictions you made in Table 1 with your findings in Table 2. Were your predictions good?

PURPOSE
To simulate a field trip for collecting rocks and identifying areas of regional metamorphism.

Excursion 3-4
A Field Trip in the Classroom

Metamorphic rocks are rocks that have been changed because of increases in temperature and pressure. This process is called *metamorphism*. Any rock may be subjected to metamorphism. In this excursion, you are going to imagine that you are on a field trip in an area where metamorphic rocks are found. After collecting the rocks, you will return

to the laboratory to study and examine the rocks you collected. This is what a geologist would do. To do this, you will need the following:

1 eye dropper	1 metal file
1 piece of cellulose acetate film	Rock samples 05, 16, 18, 20 (two of each)
1 bottle of acetone or nail polish remover	1 piece of fine sandpaper
1 hand lens	1 pan of clean sand

In your Record Book you will find a map of Natural World Village, U.S.A., similar to the one below.

MAJOR POINTS

1. Any rock may be subjected to metamorphism, which changes it.
2. The texture of a rock may be studied by making an acetate peel of it.
3. Areas of regional metamorphism may be identified by the changes that have taken place in the rocks from the areas.
4. Regional metamorphism is the term used when large areas of the earth's crust are changed by pressure and temperature.

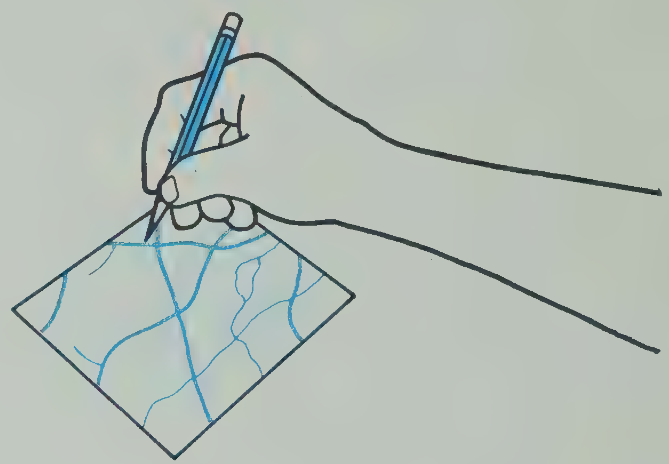
EQUIPMENT

See student equipment list. Note that acetone is preferable to nail polish.

Figure 1

The four rock samples are gneiss (05), shale (16), slate (18), and schist (20). They illustrate the progression of transformation of a sedimentary rock (shale) through successive steps under heat and pressure to metamorphic forms of slate, then schist, and finally gneiss. Under the most intense pressures, a type of granite may be produced as the final step beyond gneiss. Some geologists feel, therefore, that the granite, which was once believed to be entirely igneous, may be formed by metamorphic processes as well.

ACTIVITY 1. For each of the geology stops listed below, imagine you are in the field collecting samples of rocks. Using the directions at each stop, locate that spot on the map and record on the map the identification number of the rock sample. Use the map in your Record Book.



Stop #1 At the north end of unimproved dirt road about 1.5 km from west end of Iggy Road. Specimen fragment 16 collected here.

Stop #2 Intersection of Iggy Road and Nature Highway 21. Sample 18 collected here.

Stop #3 Intersection of Nature Highway 21 and East Street. Sample very similar to 18 collected here.

Stop #4 Intersection of East Street and an unimproved dirt road. Sample similar to 16 collected here.

Stop #5 Intersection East Street and Iggy Road. Sample 20 located here.

Stop #6 Right edge of map and East Street. Sample 05 collected here.

Stop #7 Intersection of Lake Street and Lake Creek. Sample similar to 20 found here.

Stop #8 Intersection of Lake Street and the light-duty road. Sample similar to specimen 05 collected here.

When you have finished your imaginary field trip, make sure you have recorded the sample numbers on the map at each of the eight stops. Although you made eight stops, you should only have four different kinds of rock, since you collected two samples of each kind.

ACTIVITY 2. Draw a line from the upper left corner of the map to the lower right corner of the map in your Record Book. Place each rock sample at the station from which it was collected.

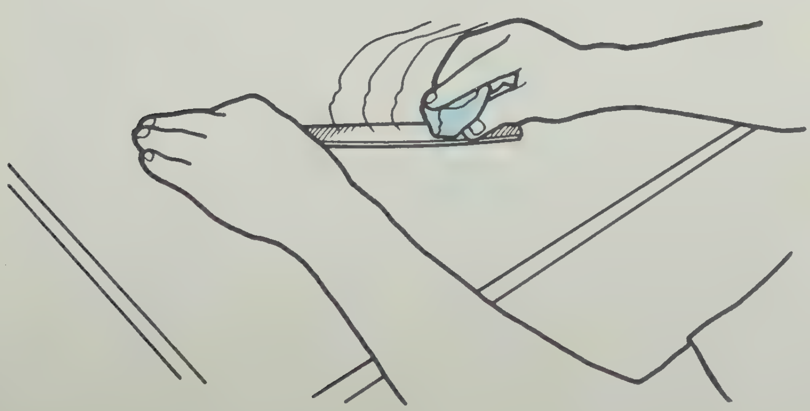
□ **1.** If you start from the upper left-hand corner and move along the line to the lower right, what major differences among the rocks do you note?

If you examine the rocks in the upper left part of the map, you will note that they are sedimentary, and as you move toward the lower right they grade into metamorphic rocks. You should have noted that as you move toward the lower right the rocks become more layered or banded, and the minerals in the rocks become larger.

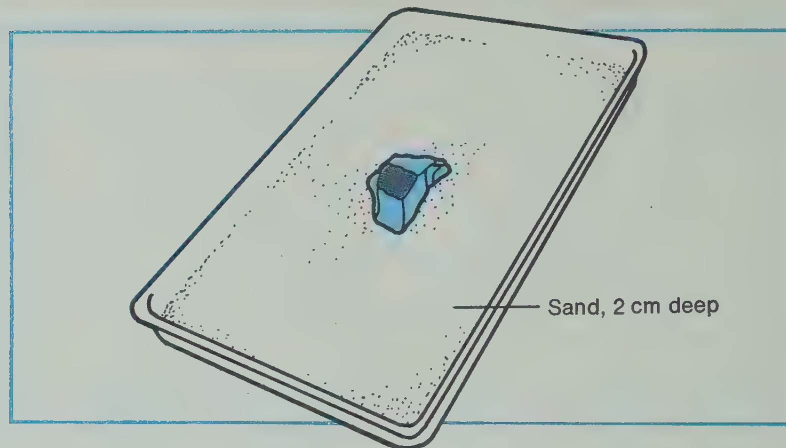
Let's examine each of these rocks more closely. Geologists sometimes study rocks by making an acetate peel of the rock. Pick up rock 05 and examine it carefully, looking for a flat, polished surface. If your rock does not have a polished surface, then you will have to polish it by following the instructions in Activity 3. If it is polished, skip Activity 3 and start Activity 4.

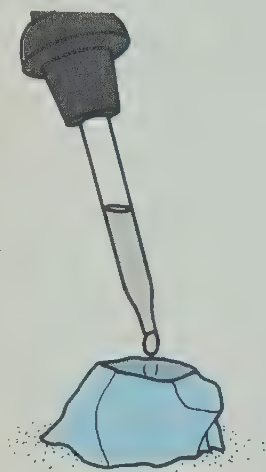
Note that the polishing procedure in Activity 3 needs to be done only once for each rock sample. Once done, the polished rocks may be used by other students.

ACTIVITY 3. Hold the rock in your hand so that the surface to be polished faces outward. Lay a steel file flat on the desk and grind the surface of the rock on the file for a few minutes. The area you grind should be at least 1.5 cm square. When you think the surface is fairly smooth, use fine sandpaper instead of the file. When the rock is finely polished, wash it in water and let it dry.



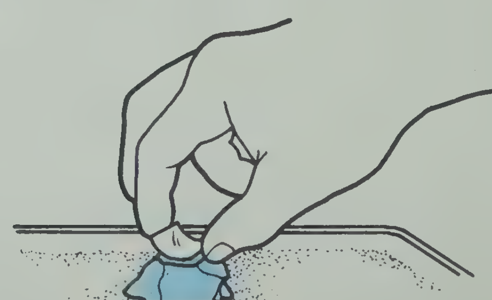
ACTIVITY 4. **Put the rock sample into a pan containing clean sand. Gently push the rock part way down into the sand. The polished surface should be face up and horizontal.**





ACTIVITY 5. **Carefully wet the polished surface with a few drops of acetone or nail polish remover.**

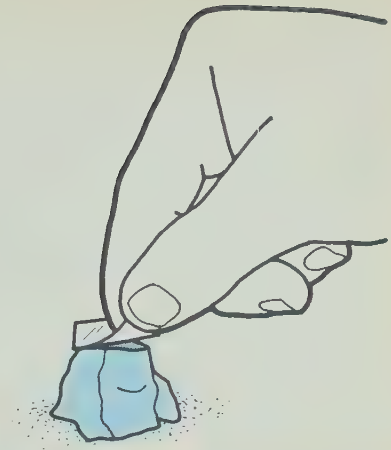
ACTIVITY 6. **Hold the acetate film between thumb and fore-finger of each hand and bend downward into a U shape. Apply to the rock so that the base of the U is first to touch the wet surface. Progressively roll the film out so that it is flat on the rock.** ***Do not press*** **directly with your fingers. Let this dry for about 15 minutes.**



The acetate film should be cut only slightly larger than the polished surface of the rock. There is sufficient acetate to supply all the students in several classes if care is taken to conserve materials.

While the first rock is drying, repeat Activities 3 through 6 for the other rocks.

ACTIVITY 7. After 15 minutes, carefully lift off the peel by grasping one corner with your finger and gently lifting. The acetate should peel off.



When you have made four peels, examine them carefully with a hand lens. Using the peels, answer the following questions.

☐ **2.** What differences do you note in the size of the minerals in the four rocks?

☐ **3.** What differences do you note in the arrangement of the minerals in the four rocks?

2 and 3. The grains should get larger as the samples go from shale to gneiss. Also the arrangement of minerals should progress from uniform grains in shale and slate to flaky schist and then to banded gneiss.

You have already learned that metamorphic rocks originate when rocks are changed by conditions of high temperature and pressure. This occurs where the temperature is not high enough to melt the material completely.

Let's assume that the three metamorphic rocks in this activity were originally the same kind of sedimentary rock you collected in the upper left regions of the map. This sedimentary rock is called shale. Shale is made of very fine particles of silt and clay. You should have noted from the peels that the grain size of the minerals of the rocks increased as you moved toward the southeast regions of your map. Also the appearance of a layer or bands became more pronounced as you moved toward the southeast.

The results of this excursion may be difficult to see; the important thing is for students to get a feel for the technique.

☐ **4.** Which region on the map do you think was subjected to the highest temperatures and pressures?

The type of metamorphism you are studying here is called *regional metamorphism*. This means that metamorphic rocks generally occupy large areas on the earth. These rocks form deep in the crust. The fact that you collected them on the surface indicates they were uplifted and the rocks above them were eroded away. It is generally agreed that rocks with pronounced layering or banding have undergone more change than other rocks. Perhaps the highest temperatures and pressures occurred in the southeast region of the map.

One possible cause of metamorphism is the presence of great masses of rocks buried deep in the crust, known as igneous intrusions. One theory is that these provide the high temperatures necessary to metamorphose neighboring rocks.

Excursion 4-1 is keyed to this chapter.

Shaping Up Mountains

4

CHAPTER EMPHASIS

Students are introduced to theories describing some of the formative processes of mountain-building.

FILMSTRIP KEY

Enrichment
Erosion and the Hydrologic Cycle
Folding and Faulting

EQUIPMENT

4 bricks
Copper sheet
1 masonite board, 25 cm × 25 cm
2 strips magnesium ribbon, 6 cm long
1 pair tweezers
30 cc ammonium dichromate, $(NH_4)_2Cr_2O_7$
4 strips of modeling clay, 10 cm × 3 cm × 1 cm, in 2 different colors (2 of each color)
Sheet of paper
Block of wood
Knife
Wooden matches
2 rulers

MAJOR POINTS

1. Some cone-shaped mountains were formed by volcanic activity and are made of layers of lava and ash.
2. Lava may flow out of fissures, or cracks, in the earth's crust and cover large areas on the surface.
3. Two different sets of forces act on mountains—uplift and wearing away.
4. If mountains are being uplifted faster than they are wearing away, they have sharp features and may be considered young.
5. If mountains are wearing away faster than they are being uplifted, they have rounded features and may be considered old.
6. No single model can account for the formation of all mountains.
7. The type of rock and general shape are clues to the formative process of mountains.

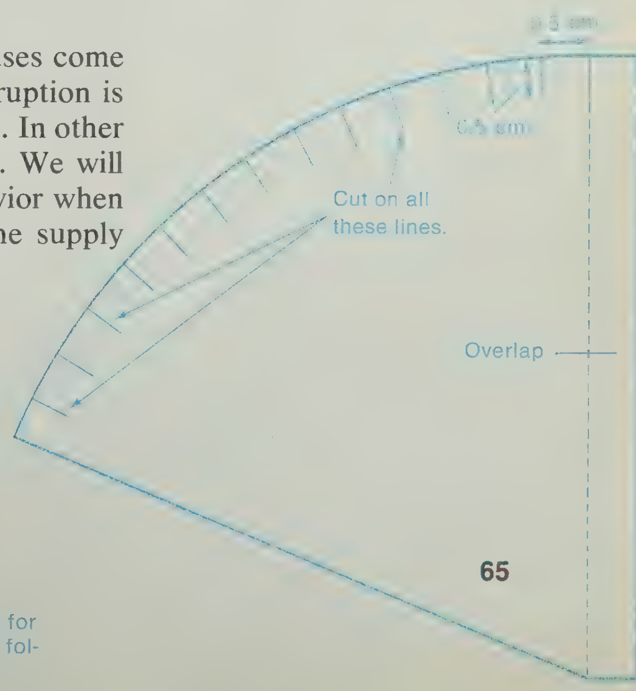
In this chapter you will take a brief tour of the mountains in the United States. On this tour, you will see how the mountains formed and why they look the way they do.

There is no more dramatic mountain-building process than an erupting volcano. We have no active ones in the continental United States, but we do have active volcanoes in Hawaii. The picture on the opposite page shows an active volcano.

☐ **4-1.** What evidence is there that this volcano is active?

During a volcanic eruption, molten rock and gases come to the surface of the earth. In some cases the eruption is very violent, sending molten rock high into the air. In other volcanoes hot rock pours slowly out of the vent. We will use a simple model of a volcano to study its behavior when it erupts. Obtain the following materials from the supply area:

1 copper cone
1 masonite board, 25 cm × 25 cm
2 strips magnesium ribbon, 6 cm long
1 pair tweezers
30 cc ammonium dichromate, $(NH_4)_2Cr_2O_7$
4 bricks
Wooden matches



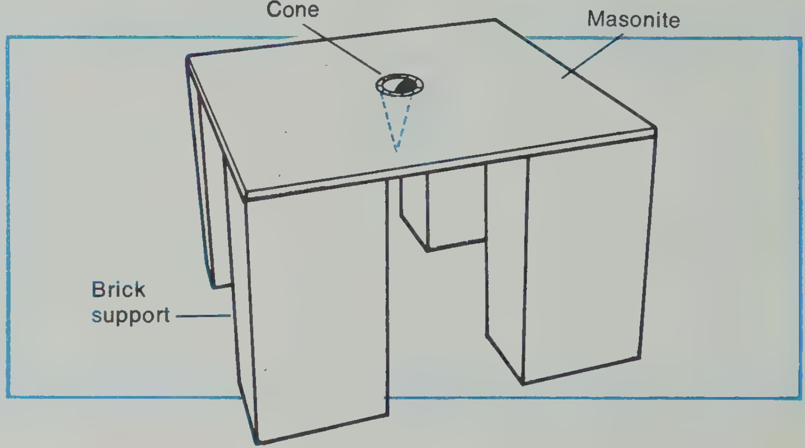
This diagram is provided as a template for making the copper cone (directions on following page).

The proper construction of the copper cone, fitted into the masonite or plywood board, can be tricky. But one or two well-made models can be used and reused by the whole class. The following procedure should help:

1. Cut a circular hole 2.5 cm in diameter in the board. Perhaps the school shop can help with this step.
2. Cut a piece from the copper sheet, using the figure on page 65 as a template.
3. Cut in on the curved line 0.5 cm deep every 0.5 cm along the curve, as shown.
4. Roll the cone so that the copper overlaps 0.5 cm at the curved edge to the line shown on the template. Fasten with small pieces of tape.
5. Bend the 0.5-cm cuts out so that they form a lip around the open end of the cone.
6. Support the board with the hole in it on the four bricks. Insert the cone snugly into the hole, with the tabs flat on the board. Make sure that the overlap is tight together all the way to the tip of the cone.
7. It would be wise to have protection under the tip of the cone so that molten material cannot damage the table. Another brick will work fine.

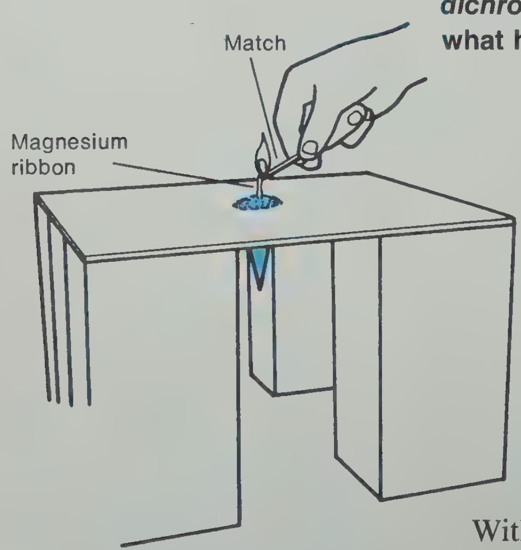
The magnesium ribbon will ignite more easily if the end of the ribbon is slit in two or three places. (Visualize a fringe.) Make the slits about 0.5 cm long.

ACTIVITY 4-1. With your partner, set up the apparatus as shown in the diagram. Fill the cone to the top with ammonium dichromate. *Do not pack down.* Using tweezers, insert a 6-cm strip of magnesium ribbon into the cone. Leave about 2.5 cm exposed above the dichromate.



Caution *Keep your face and hair away from the cone. Avoid touching the powder. Remember your safety glasses.*

ACTIVITY 4-2. In a dimly lighted room, ignite a match and carefully bring it to the ribbon. *Do not touch the match to the dichromate.* When the ribbon ignites, stand back and observe what happens.



SAFETY NOTE: These activities should be done under close supervision. You may want to consider performing them yourself, with small groups of students who arrive at this point together. In addition to the potential danger, they are extremely messy (see "Preparation of Equipment" in the front of the text).

The first trial is best done in a dimly lighted room. The second trial may be done with normal lighting.

Without disturbing the powder on the masonite board, refill the cone with ammonium dichromate. Insert a fresh piece of magnesium ribbon. Repeat Activity 4-2.

ACTIVITY 4-3. At eye level with the masonite board, sketch a diagram in your Record Book, showing what the volcano looks like from right to left. As an aid, imagine walking from points A to B across the volcano.

MONO CRATERS, DOMES, AND SILLS

About 320 kilometers north of Death Valley is a set of mountains that look quite similar to the ones you've looked at so far. The Mono craters are a group of about 20 domes, several of which appear in Figure 4-1. A single Mono crater is shown at A in Figure 4-1, while a trio is shown near B.

Mono craters lie due east of Yosemite National Park, and south of Mono Lake. A little farther north there are extensive hot springs, indicating continuing vulcanism.

Figure 4-1

If you were to look at the trio of craters more closely, they would resemble the drawing in Figure 4-2. You will notice that each dome contains a shallow hole at the top.

☐ **4-2.** How do you think the Mono craters are formed?

Figure 4-2

In the supply area are some specimens (number 10) of rock like the ones in the Mono crater area. Examine one or more of these carefully.

Specimen 10 is rhyolite, a fine-grained igneous rock called an extrusive, meaning that it was formed above ground.

☐ **4-3.** Based on your knowledge of rocks, what clue does the texture of the rock give you as to the origin of the rock?

In the western part of the United States, you can find cone-shaped mountains, some of them with craters in the top. The cinder cone (Figure 4-3) at Lassen Volcanic National Park, California, is typical. The rock in these mountains is igneous. This means that it has cooled from molten rock. The rock may be alternately layered with ash.

☐ **4-4.** What evidence is there that the mountain in Figure 4-3 is volcanic?

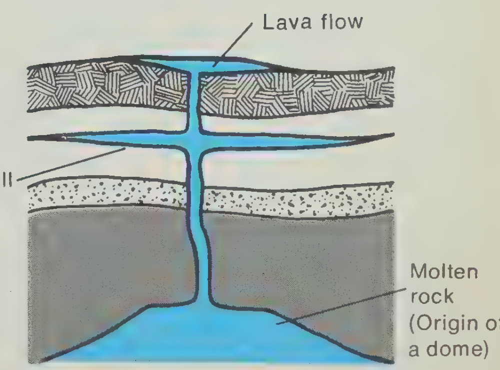
Figure 4-3

The shape and the rock type are evidence that these cone-shaped mountains were once volcanoes. But not all lava flows form cones. Sometimes the lava reaches the surface through cracks in the earth's crust. The Columbia plateau in the northwest United States is covered by layers of igneous rock over an area of 500 000 square kilometers, as shown in Figure 4-4. Although there are several cone-shaped mountains in this region, the lava coming from them could not have covered such a vast area. Instead, most of the lava is believed to have poured out of long cracks, called *fissures*. (See Figure 4-5.) The lava that poured out of these fissure volcanoes formed a hard, fine-grained igneous rock. It has properties similar to those of the volcanic rock that is still being formed by present-day volcanoes, such as Mauna Loa in Hawaii.

This igneous rock, when it is broken up by weathering, has a high nutrient content and supports many forms of plant life. Consequently, much of the Columbia plateau is covered with vegetation, and the lava-flow nature is not always readily apparent.

Figure 4-4

Figure 4-5



☐ **4-5.** Why is the igneous rock from fissures fine-grained?

Not all the molten lava that flows through the cracks gets to the surface. Sometimes it gets trapped in horizontal cracks, where it cools and hardens slowly to form *sills*. If you are interested in learning more about sills, look over **Excursion 4-1** "Igneous Intrusions."

☐ **4-6.** What type of rock is found in lava flows and sills? What difference would you expect to find in the grain size of rock samples from each?

One of the most interesting mountains in the country lies just outside of Atlanta, Georgia. It is called Stone Mountain (see Figure 4-6). This 200-metre-high dome was once molten rock under the earth's crust. (Look back at Figure 4-5.)

Figure 4-6

The rocks that make up Stone Mountain are quite different in appearance from the rocks you examined from the Mono craters. In the supply area you will find samples (number 07) of rocks like those from Stone Mountain. Compare these samples with the Mono crater rocks.

4-7. Both are igneous rock, but the Mono sample (rhyolite) was formed on the surface from molten material, while the Stone Mountain sample (granite) was formed deep within the earth, under heavy pressure, and with slower cooling.

☐ **4-7.** What do the differences in these rocks tell you about how and where the Stone Mountain samples were formed?

You can see from the rock sample why this dome mountain stands alone in such flat country. It's made of the hardest rock around. The rock that originally surrounded and covered it has long since eroded away.

OLD AND YOUNG MOUNTAINS

Like all other earth features, mountains have ages. Some are old, others are young. And they grow and die all the

time. Compared with other earth features, an active volcano is but a child.

☐ **4-8.** Which mountains appear older—those shown in Figure 4-7 or those in Figure 4-8? Why?

The problem in determining the age of a mountain is that two quite different sets of forces must be considered. At the same time that mountains are being pushed up from below, they are being worn down from above by water, wind, and ice. What you see as you look at a mountain is the result of both these sets of forces.

Figure 4-7

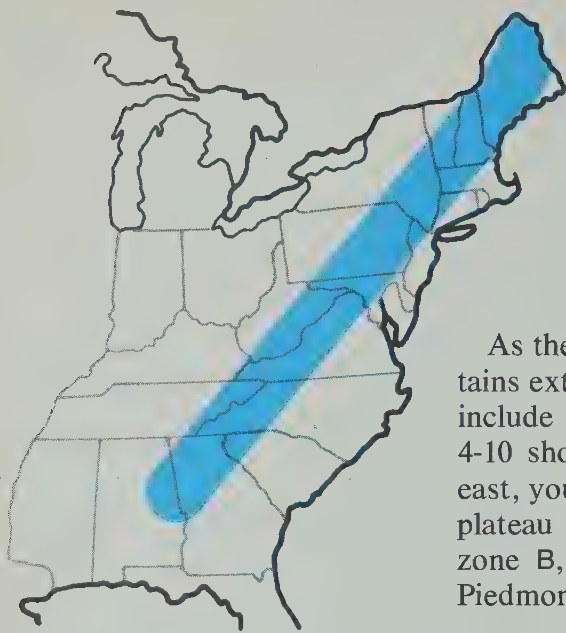
Figure 4-8

If the uplift has been quite a bit greater than the wearing away, you should expect high peaks, steep mountain sides, deep narrow valleys, and swiftly flowing streams (Figure 4-7). You might think of such mountains as ''young.'' The mountains shown in Figure 4-7 began ''growing'' about 70 million years ago and are still being uplifted today.

On the other hand, if wearing away has exceeded uplift, or if uplift has stopped, you find rounded hills and broad valleys (Figure 4-8). These are ''old'' mountains. The ones shown in Figure 4-8 are believed to have stopped ''growing'' about 230 million years ago.

By these criteria, the older mountains in the United States are the Appalachians, which are composed of the Adirondacks, Green Mountains, Catskills, Smokies, and others. The younger mountains would include the Rockies, and the Andes in South America. The youngest would probably be the Cascades and Sierras, along with the Alps in Europe.

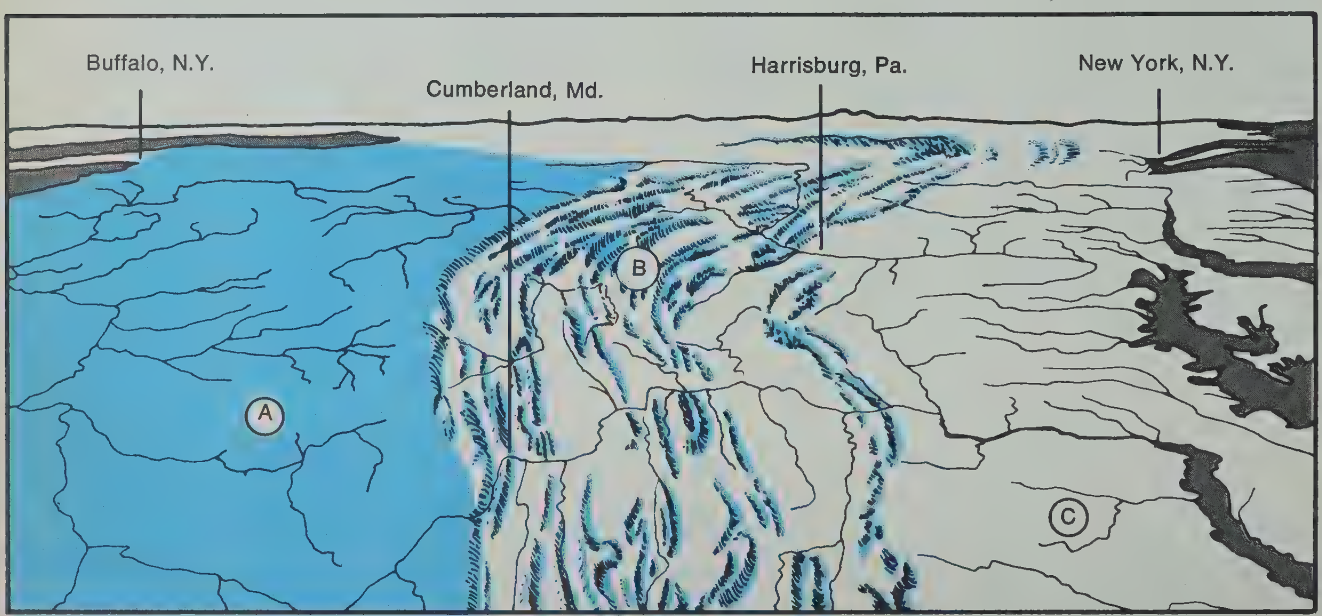
Figure 4-9



□ **4-9.** What is the most obvious difference between new and old mountains?

As the map in Figure 4-9 shows, the Appalachian Mountains extend over much of the eastern United States. These include the oldest mountains in the United States. Figure 4-10 shows a more detailed view. Reading from west to east, you can identify three zones: zone A, the Appalachian plateau consisting of flat, gently tilted sedimentary rock; zone B, a series of ridges and valleys; and zone C, the Piedmont and coastal plains.

Figure 4-10



The Great Smoky Mountains, consisting mainly of metamorphic and igneous rocks, lie to the south (below the lower border of the map).

Let's focus on zone B, the ridges and valleys of the Appalachians. How might these ridges and valleys have been formed?

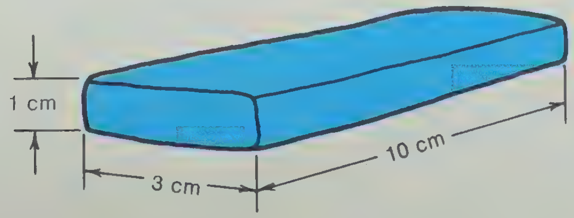
The earth's crust actually appears to have been pushed up to form the mountains. One theory explains this in terms of the continental drift model. According to this model, plates of crust collide. Tremendous pressures are created, and these cause a folding of the earth's crust.

The photograph in Figure 4-11 shows actual folds in a railway cutting at Bakersville, North Carolina.

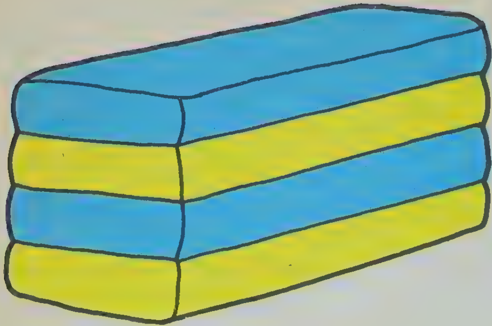
Figure 4-11

To make a model that explains layered and folded features of the crust, you will need two colors of modeling clay.

ACTIVITY 4-4. Flatten or cut the clay into strips 1 cm by 3 cm by 10 cm. Make two strips of each color.

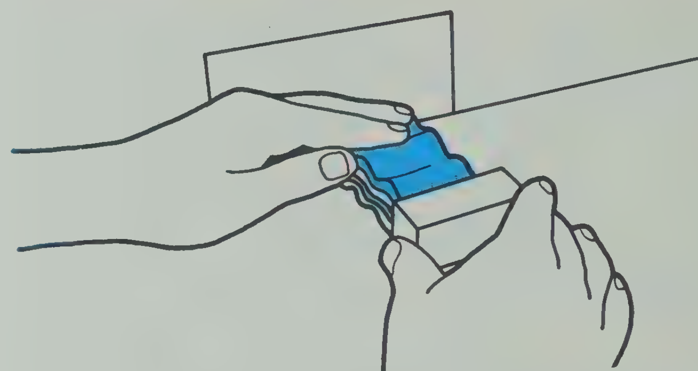


ACTIVITY 4-5. Stack the strips, alternating the colors.



After completing these activities, students will need to separate the individual colors of clay for further use. The clay will be able to be used longer if students are told not to press the layers too tightly together. You may, in fact, wish to have the students place a square of waxed paper between the layers of clay, to make separation easier. Impress students with the necessity of saving all the modeling clay that is cut out. If this is not done, you will rapidly deplete your supply of clay.

ACTIVITY 4-6. Place the narrow end of the clay block against the wall, protecting the wall with a piece of paper. Place a block of wood at the opposite end. Steady the block with one hand. With the other hand, push the clay block hard and steadily.

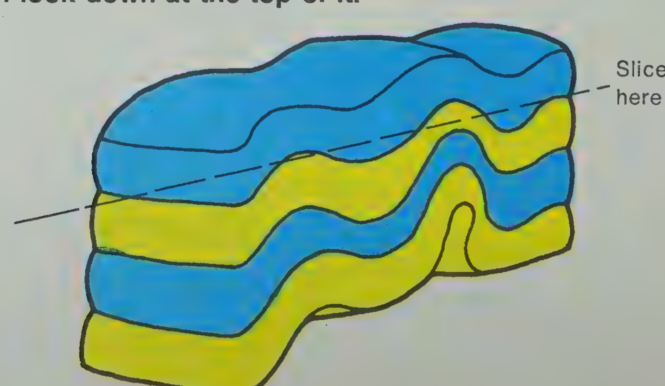


☐ **4-10.** What happens to the clay model?

Look carefully at the side of the clay block. The layers represent beds of sediments. The dips represent valleys and the humps, mountains.

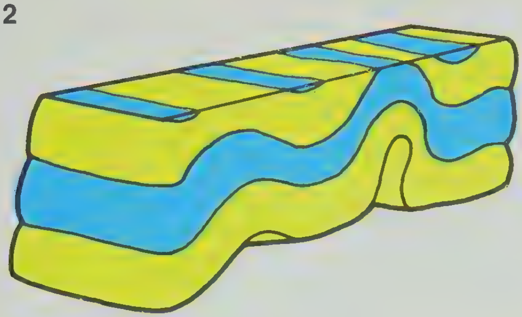
When you look at the earth, you cannot always see the folding this clearly because a side view is not always exposed. But sometimes there is other evidence of folding.

ACTIVITY 4-7. Slice off the top one fourth of your clay block. Then look down at the top of it.



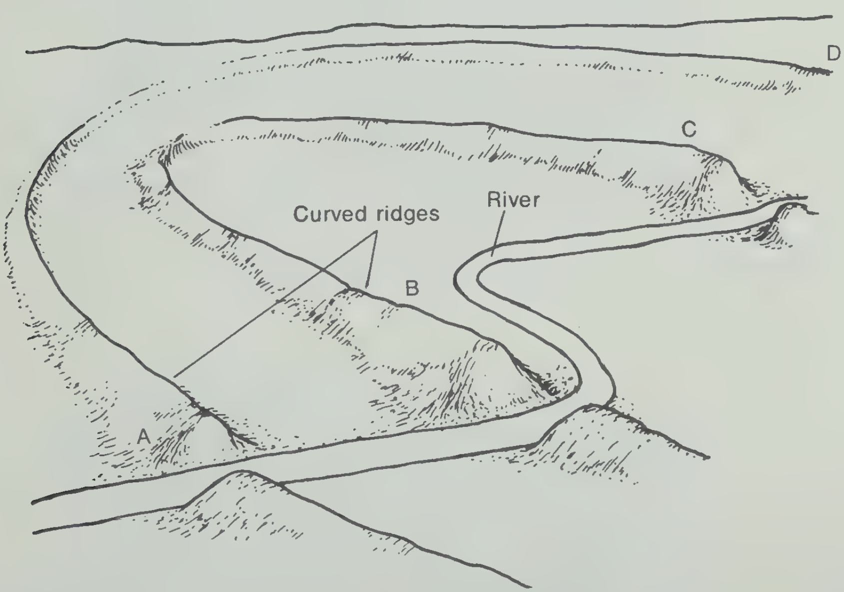
□ **4-11.** What evidence do you see of folding in Figure 4-12?

Figure 4-12



The Appalachian region of the United States has many folds. Figure 4-13 represents the shape of the land near the Susquehanna River around Harrisburg, Pennsylvania. The curved ridges and rocks on each side of the river give evidence that layers of rock were folded.

Figure 4-13



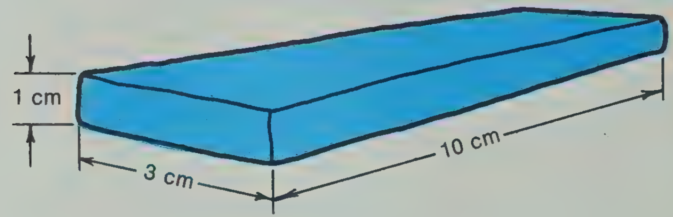
Unlike the Appalachians, the Rocky Mountains and the Sierra Nevada are young mountains. High in these mountains, several thousands of metres above sea level, there are layers of sedimentary rock. Remember, sedimentary rocks are formed in the sea. How can you explain their appearance at the top of a mountain? One explanation is that the

The Sierra Nevada is the upper edge of a huge sloping platform about 650 km long and from 65 to 125 km wide. When approached from the California coast, the slope is rather gentle; when viewed from the Death Valley side, the fault forms steep precipices.

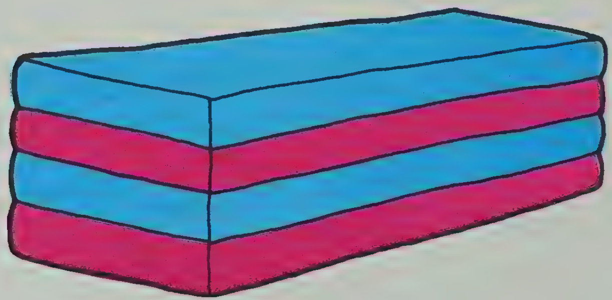
earth must have been pushed upward for a very long period of time. In Activities 4-8–4-11, you will look at a model of how this uplifting may have come about.

Get two colors of modeling clay, a knife, and two rulers.

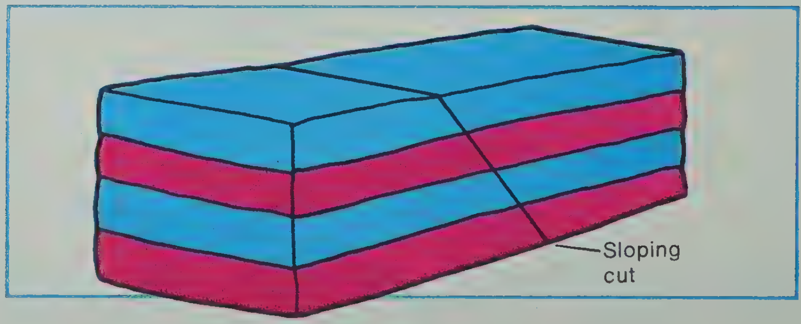
ACTIVITY 4-8. From each colored piece of clay, cut two thin strips, as you did in Activity 4-4.



ACTIVITY 4-9. Let each strip represent a layer of sedimentary rock. Place one on top of the other, alternating the colors, to make a block.

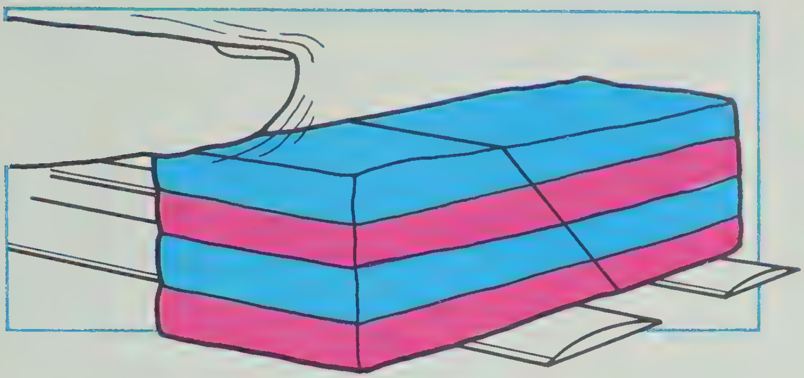


ACTIVITY 4-10. Cut a sloping crack as shown.



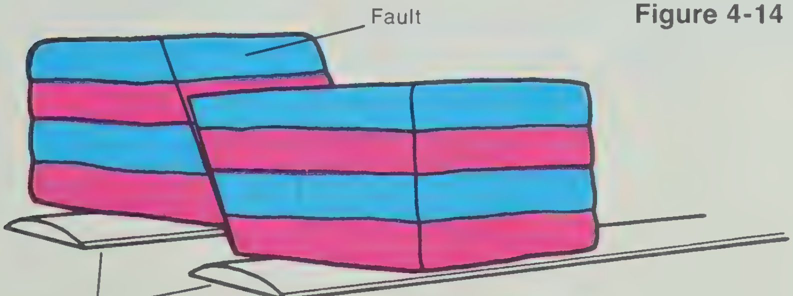
ACTIVITY 4-11. Press the two pieces together again so that they just barely hold together. Support the block on two rulers. Press down on one end of the block and vibrate the block

slightly as you push. Gently vibrate and push until the cut surfaces begin to slide apart.



If you were careful in following directions, your block should now look like the sketch in Figure 4-14. Notice the boundary between the two sections that slid apart. This is what geologists call a *fault*. Compare your clay model with Figure 4-15. Can you identify the fault in this picture?

Figure 4-14

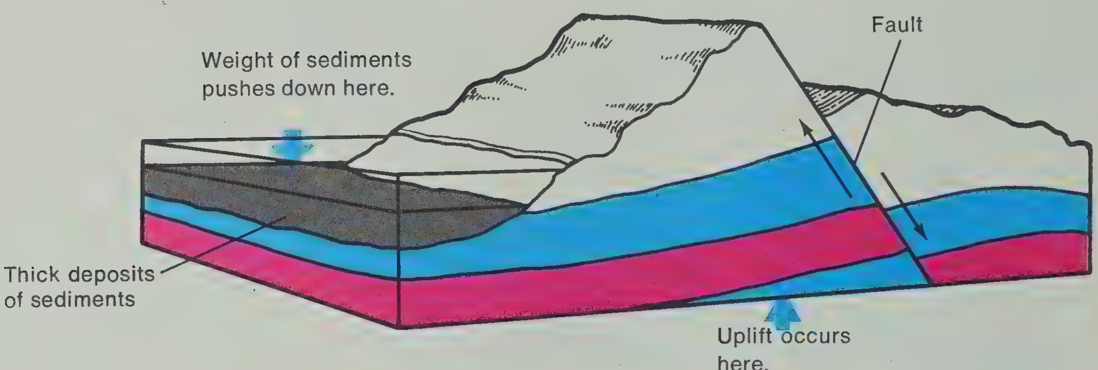


Sometimes one of the folded layers is a coal seam (another sedimentary rock). In another case it may be a layer of gypsum the raw material of plaster.

Figure 4-15

According to the theory, two conditions are necessary for the formation of mountains like those in Figure 4-15. There must be a zone of weakness, or crack, in the rocks, and there must be a strong downward force some distance away. The downward force makes one section of rock slip away from the other at the weakest section. The diagram in Figure 4-16 shows how faults can cause mountain uplift in such areas as the Sierra Nevada in California. In this model, the downward force that caused slippage was the great weight of sediments on the ocean floor.

Figure 4-16



☐ **4-12.** Sea shells are commonly found in rock more than 2000 metres above sea level in the Appalachian Mountains. How can you explain this?

SEARCHING FOR A MODEL

You have studied several models that deal with uplift of the earth's surface. You have also studied several types of mountains. Table 4-1 summarizes the information about each kind of mountain you investigated.

See descriptions of the continental drift model and the sea-floor-spreading model.

☐ **4-13.** Choose one kind of mountain from the table, and explain its formation on the basis of one of the models you have studied.

Table 4-1

	Types of Rocks	Origin of Rocks	Shape of Mountains
Block-fault (Rockies and Sierra Nevada)	Sedimentary and metamorphic	Marine deposits	Linear; wedge-shaped
Mono craters	Igneous	Cooling of molten material at the surface of crust	Round
Stone Mountain	Igneous	Cooling of molten material beneath the crust	Round
Valley and ridge of Appalachians	Sedimentary	Marine deposits	Linear; folds

Before going on, do Self-Evaluation 4 in your Record Book.

Excursion 4-1
Igneous Intrusions

PURPOSE

To illustrate, by means of clay models, the formation of igneous rock in cracks beneath the earth's surface.

EQUIPMENT

4 strips of modeling clay, 6 cm × 6 cm × 1 cm (2 of each color)
Block of modeling clay of third color
Knife

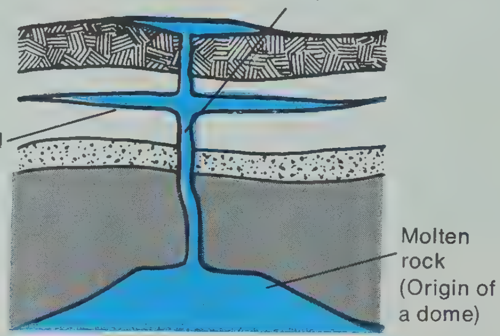
MAJOR POINTS

1. The crystal size of igneous rock depends on where the rock cooled.
2. Sills, dikes, and domes are formations of igneous rock.
3. A horizontal layer of rock between two other rock layers is called a sill.
4. Igneous rock that has been trapped in a vertical crack is called a dike.

When molten rock flows out onto the earth's surface through cracks in the earth's crust, it forms a layer of lava. This lava cools to a fine-grained crystalline rock. If the molten rock is trapped within the earth's crust, it cools more slowly, allowing larger crystals to form. Such rock is called an *igneous intrustion*.

Intrusions take different forms, depending on where the molten rock has been trapped. If the molten rock is trapped in a horizontal crack, it forms a rock layer called a *sill*. If trapped in a vertical layer, it forms a *dike*. A dome like Stone Mountain, shown earlier in Figure 4-6, is another kind of igneous intrusion. Domes are formed far below the earth's surface.

Figure 1



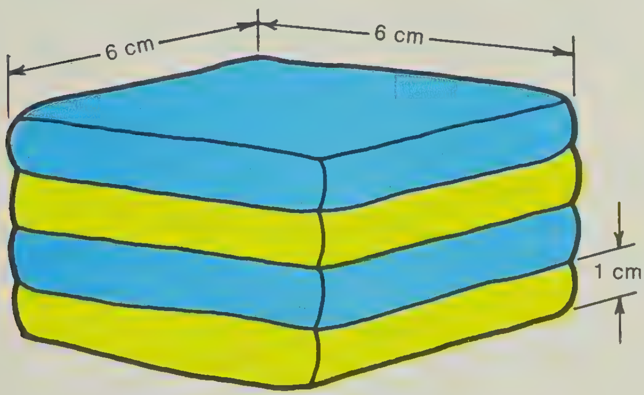
Sometimes, igneous intrusions can be seen in rock outcroppings. The dark bands in Figure 2 are intrusions in a cliff in Glacier National Park, Montana.

Figure 2

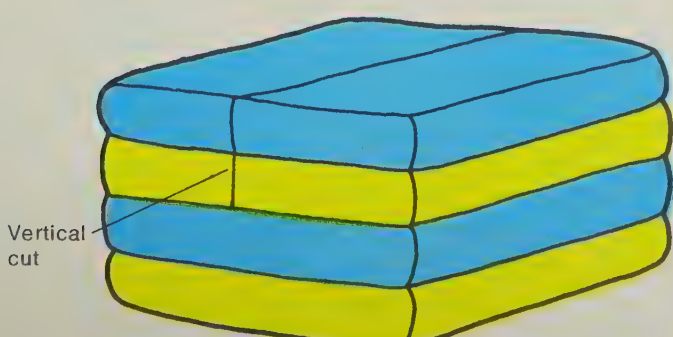
☐ **1.** Which kind of igneous intrusion do you think the dark bands in the photograph are?

In this excursion, you will make a clay model to help you visualize dikes and sills. You will need a knife and three lumps of clay, each of a different color.

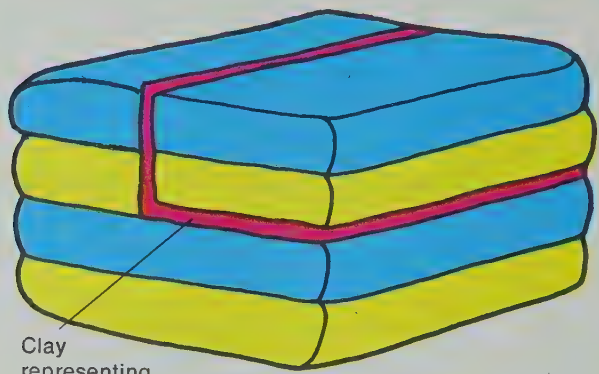
ACTIVITY 1. Cut two strips of modeling clay of one color, 6 cm by 6 cm by 1 cm. Cut two strips of the same size out of another color clay. Make the four strips into a block, alternating the colors as shown. The strips of clay represent layers of sedimentary rock in the earth's crust.



ACTIVITY 2. Use a knife to make a vertical cut into the middle of your block. The cut should go through the top two layers only.



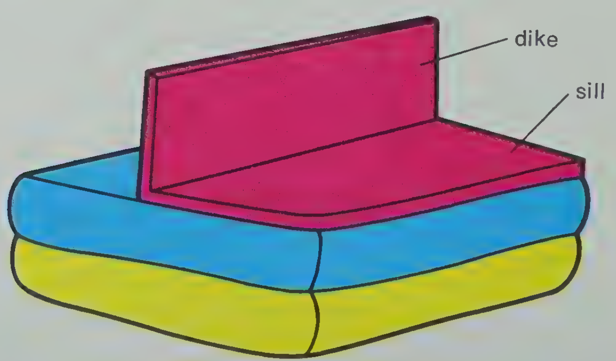
ACTIVITY 3. Take some clay of the third color. Flatten it into thin sheets about 2 mm thick. Open up the cut you made in the block, and push a thin piece of clay into it. Insert another piece of clay between the second and third layers. This piece will connect with both top cuts.



Note that the model built in this excursion is intended to show only the end result of magma, or molten rock, flowing into a crack; it does not show the origin of the magma.

Sedimentary rock generally wears away much sooner than igneous rock. You can represent this situation on your clay model by removing the upper strips of clay representing sedimentary rock layers. At some stage of erosion, your clay model will look something like Figure 3.

Figure 3



☐ **2.** Is the vertical strip of rock in Figure 4 a sill, or a dike? Explain your answer.

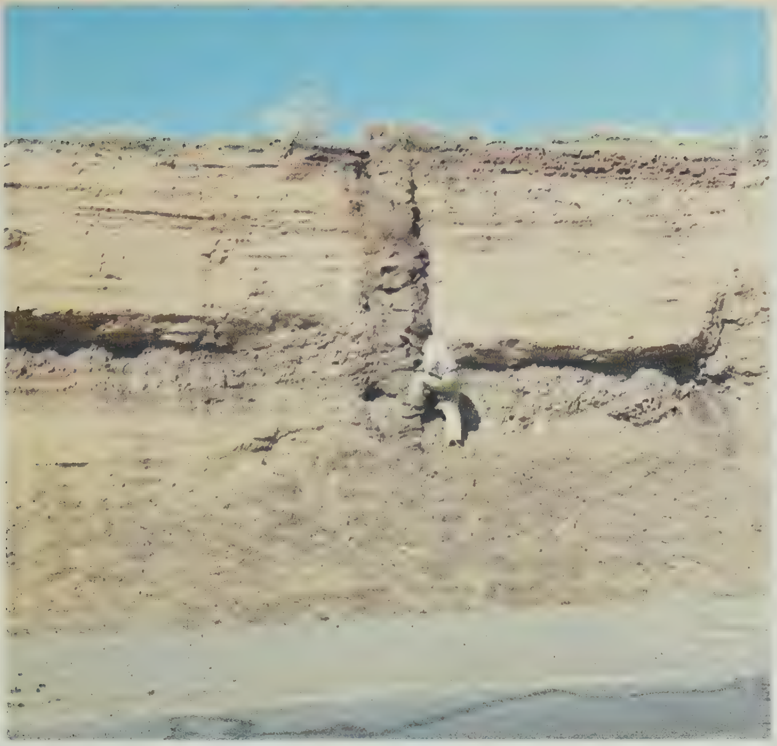


Figure 4

☐ **3.** Would you expect the strip of rock in the photograph to be igneous, or sedimentary, rock? Explain your answer.

☐ **4.** If you compared rock samples that came from a sill, a lava flow, and a dome, what differences might you expect to see?

At the end of the excursion, have students separate the clay by colors.

Carving Mountains with Ice

5

FILMSTRIP KEY

Enrichment
Erosion and The Hydrologic Cycle

Excursion 5-1 is keyed to this chapter.

EQUIPMENT (Optional)

Ice, with pebbles and stones frozen in it.
Stream table, with sand-silt mixture.

CHAPTER EMPHASIS

Student attention is focused on how mountains (and other landforms) can be sculptured by glaciers.

MAJOR POINTS

1. The size and the motion of a glacier are controlled by the relationship between the creation of new ice at the head and the rate of melting at the foot.
2. Temperature and amount of snowfall are two factors that control this relationship.
3. The terms used to describe the action of glaciers on the land are identified.
   a. The pulling of rocks from an area by a glacier is called plucking.
   b. A large bowl formed at the head of a glacier by plucking is called a cirque.
   c. If the cirque fills with water, it forms a lake called a tarn.
   d. Sharply ridged peaks formed by glacial plucking are called horns.
   e. One of the most important effects of glaciers is the carving of U-shaped valleys.
4. Valleys formed by glaciers are compared with valleys formed by streams.
   a. A fast-flowing stream cuts a narrow channel with sharp bends.
   b. A glacier cuts a wide, U-shaped path with long, smooth curves.
   c. When tributary glaciers join a main glacier, hanging valleys may be formed.

Mountains don't last forever! Up to this point, you have been concentrating on how the land is uplifted to form mountains. Let's make a slight departure and see how mountains are cut down and sculptured. The beautiful shapes of mountains were caused by the sculpturing of already uplifted materials. One way that mountains are sculptured is by glacial action. Take a look at Figure 5-1.

Notice how many sharp ridges are in this portion of the Canadian Rocky Mountains. Notice also the U-shaped valleys, the bowl-shaped basins, and the almost complete absence of flat surfaces. This kind of landscape is fairly typical of areas that have been carved by glaciers. A *glacier* is a moving river of ice. The photograph shows the remains of what was probably once a much larger glacier.

Figure 5-1

☐ **5-1.** What evidence is there in Figure 5-1 that the glacier is *not* advancing? (Hint: Compare the size of the glacier with the area that has been carved out.)

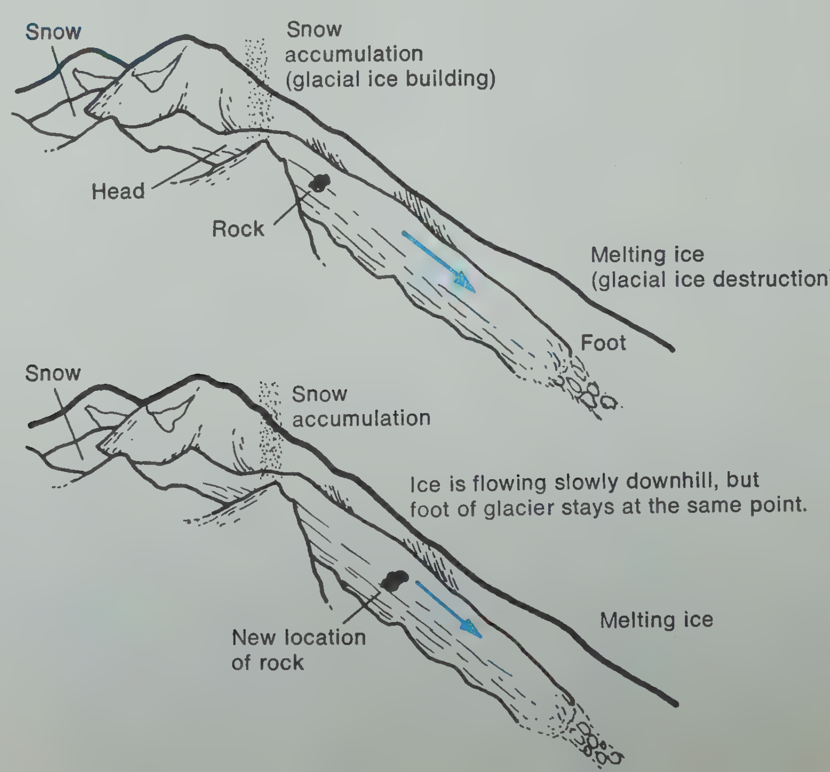
Measurements show clearly that the lower edges of glaciers may alternately move up or down the sides of mountains. Nisqually Glacier, on the side of Washington's Mount Rainier, moved back more than 1200 metres between 1857 and 1944. On the other hand, the Black Rapids Glacier in Alaska moved forward almost five kilometres during five months in 1936. What causes glaciers to retreat and advance?

Let's begin by examining what happens at the head and foot of a typical glacier. Notice that the head of the glacier in Figure 5-2 is well up the mountain slope, where cold temperatures keep snow present throughout the year. The fallen snows gradually turn to ice and add to the size of the glacier.

EXCURSION

It is interesting to see how snow is turned to glacial ice. See **Excursion 5-1** for the explanation. While the glacier grows at its head, the foot melts because of the higher temperatures lower down the mountainside. Gravity, helped by melting and refreezing of ice where it contacts rock, causes the ice to slide downward.

Figure 5-2

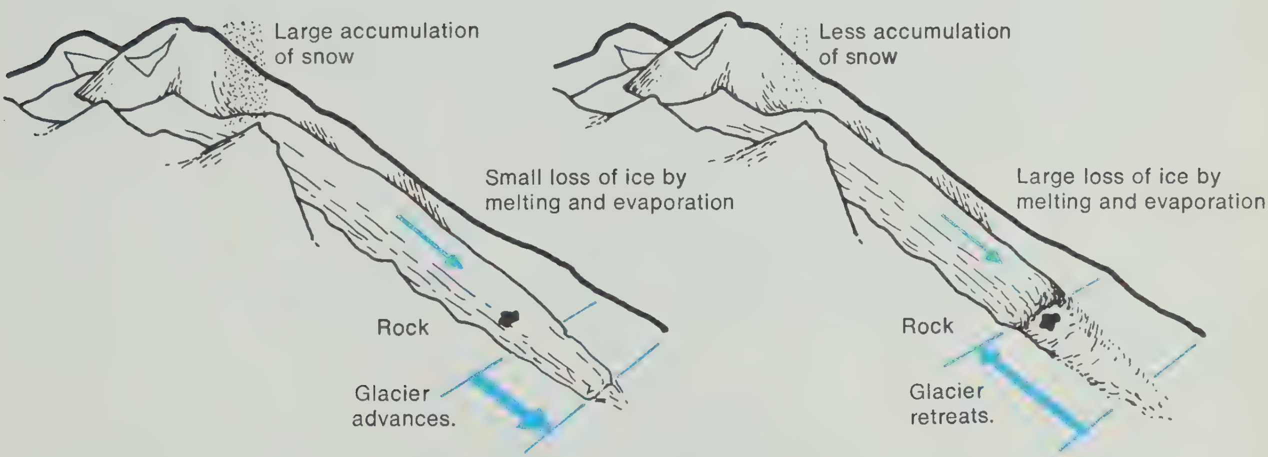


Often the creation of new ice at the head of a glacier equals the rate of melting at the foot. In this case, although ice gradually flows down the hill, the foot of the glacier remains at about the same point.

Most mountain glaciers are retreating (moving up the mountainside). Whether they will continue to retreat, or will grow again into another ice age, is an unresolved question.

☐ **5-2.** Explain how the rock shown in Figure 5-2 moves down the glacier even though the foot of the glacier remains at the same point.

Figure 5-3



Sometimes, either the rate of melting or the rate of ice buildup increases with no change in the other. Under these conditions, the foot of the glacier moves either up or down the mountainside (see Figure 5-3).

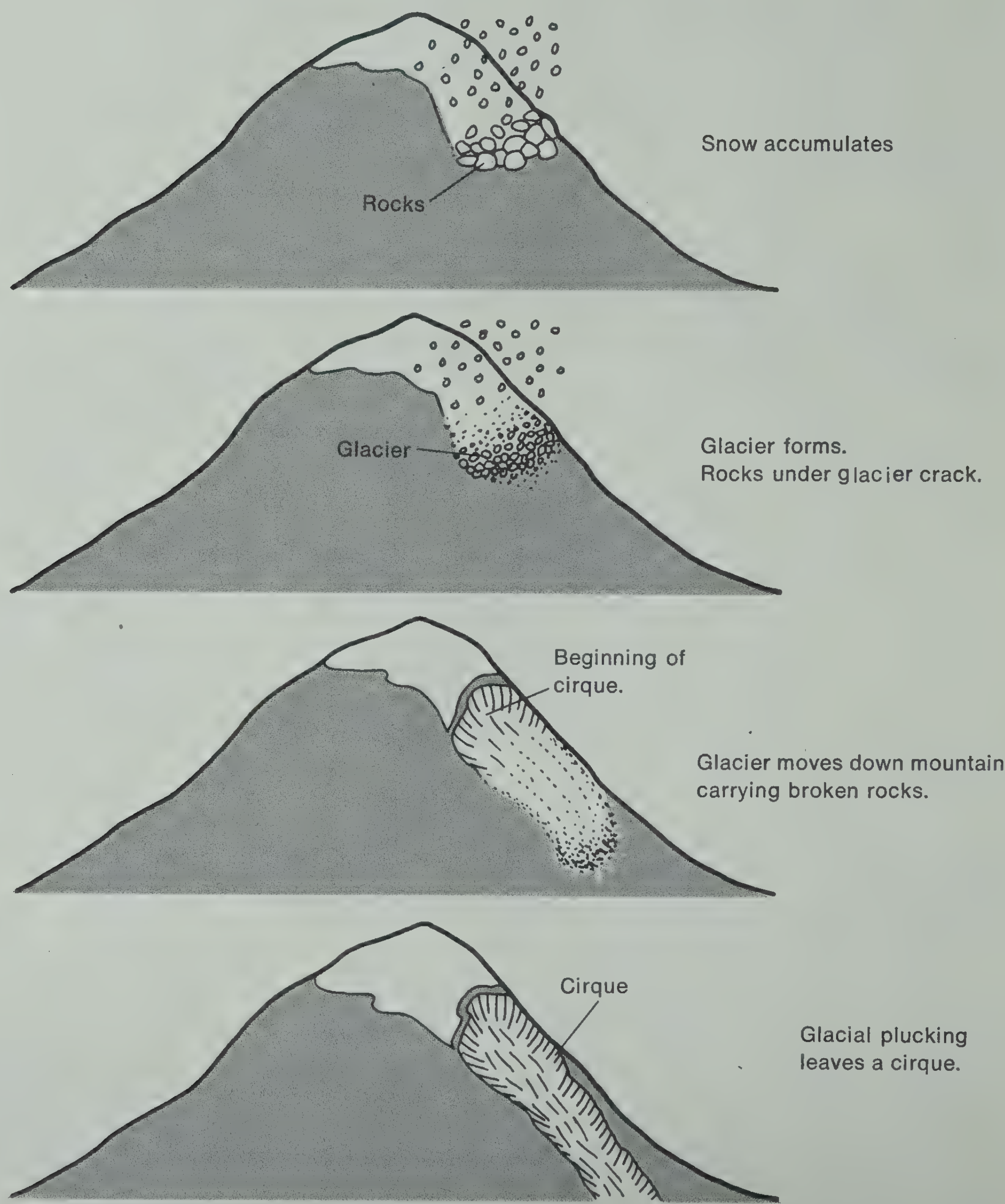
☐ **5-3.** What are the causes of a glacier's advance?

As glaciers move down a mountainside, they often pull rocks away. This is called *glacial plucking.* Over a period of time, this plucking forms a large bowl, or *cirque,* at the head of the glacier. As plucking continues, the cirque grows larger and deeper, often producing a wall many hundreds of metres high and a bowl equally deep. Melting of the glacier frequently turns the bowl of the cirque into a small lake

Sometimes glaciers are like very rough sandpaper indeed. Grooves about 0.5 m deep and 1 m wide have been identified on Kelleys Island, which is in Lake Erie, north of Sandusky, Ohio. Even deeper glacial grooves, some more than a kilometre long, 50 m wide, and 15 m deep were gouged in the rock of upper Canada.

called a *tarn*. Figure 5-4 diagrams the process by which cirques are formed. Figure 5-5 shows an actual cirque and tarn.

Figure 5-4



☐ **5-4.** How is a tarn different from a cirque?

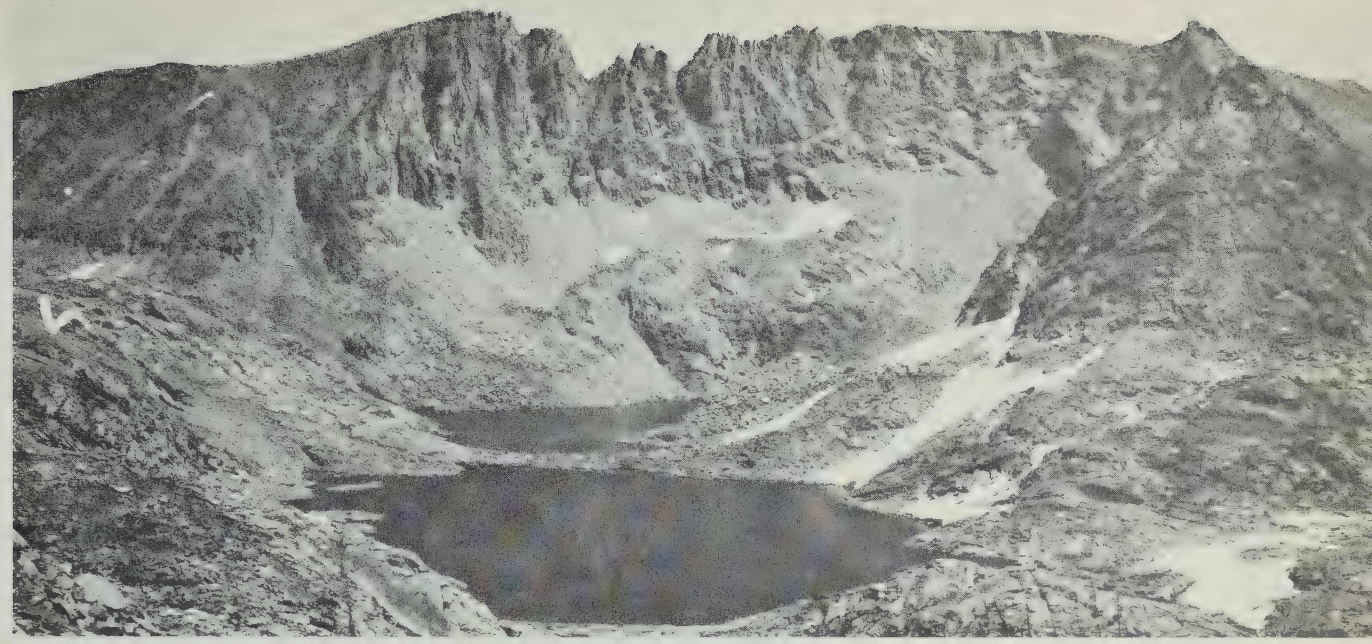


Figure 5-5

Glacial plucking often produces several cirques on the same mountain. Sharp ridges and many-sided peaks called *horns* are two results of this process. Figure 5-6 diagrams the way these features are formed, and Figure 5-7 shows a typical example, the famous Matterhorn in Switzerland.

☐ **5-5.** What features of the horn shown in Figure 5-7 suggest glaciers were involved in shaping it?

Figure 5-6

Figure 5-7

Figure 5-8

Figure 5-9

One of the most prominent features of many glacial landscapes is the huge valleys. These valleys stand in sharp contrast to the valleys carved by rivers. Compare the shape of the typical river valley in Figure 5-8 with the shape of the typical old glacial valley in Figure 5-9. Figure 5-10 diagrams these two kinds of valleys.

A fast-flowing mountain river rolls stones and pebbles along the stream bed, causing a grinding action. This digs the bed deeper along a narrow channel and cuts sharp bends.

When a glacier moves down the mountainside, it forms a huge, wide, slow-moving mass. Pebbles and boulders are embedded in the ice being dragged along. Instead of cutting downward like a saw cut, it grinds a wide, U-shaped path, which can only bend in long, smooth curves.

In Figure 5-11 you can see the wide masses of ice that form the big South Sawyer Glacier in Alaska. Notice that two tributary glaciers feed into it. Imagine the huge load of rock debris this ice is dragging along the valley floor.

Figure 5-10

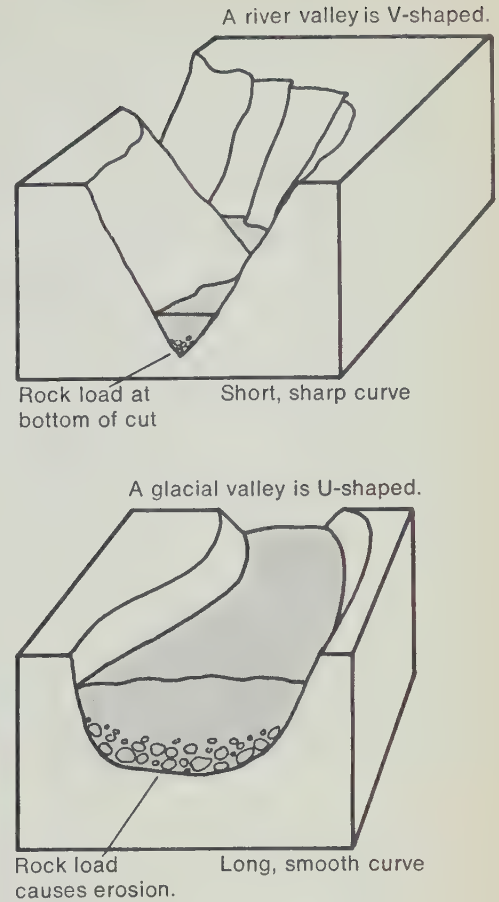


Figure 5-11

If you have access to a refrigerator, freeze a tray of ice with pebbles and stones in it. Then have students try pushing the ice through the sand-silt mixture in a stream table or large pan. Have the students compare the path carved by the "glacial ice" with the path carved by stones and pebbles rolling through a stream bed.

Figure 5-12

Note the difference between tributary glaciers and tributary rivers. In the former, the base level of each valley depends on how much ice is being carried. However, when a tributary river flows into another river, both rivers have the same valley level. The base level of erosion where the rivers join is the bottom of the bigger river.

Figure 5-12 illustrates how the landscape shown in Figure 5-11 could look in the future if the ice melted. 1 represents the U-shaped valley formed by the main glacier. 2 and 3 represent the valleys formed by the tributary glaciers. Notice that 1 is much deeper than the other valleys.

☐ **5-6.** Why, do you think, does the main glacier carve a deeper valley than its tributary glaciers?

Figure 5-13

The smaller, higher valleys are called *hanging valleys*. There are many spectacular hanging valleys in the United States. Yosemite National Park in the Sierra Nevada, California, is famous for its glacial valley landscape. Figure 5-13 shows a typical hanging valley in Yosemite. It is what remains from a small tributary glacier of the last ice age and can be seen at the right, high above the big U-shaped valley that was carved by the main glacier.

SUMMARY

Well, if you've done good work, you've learned a great deal about the way mountains took on their characteristics. You've also had a chance to think about forces that are acting upon mountains today.

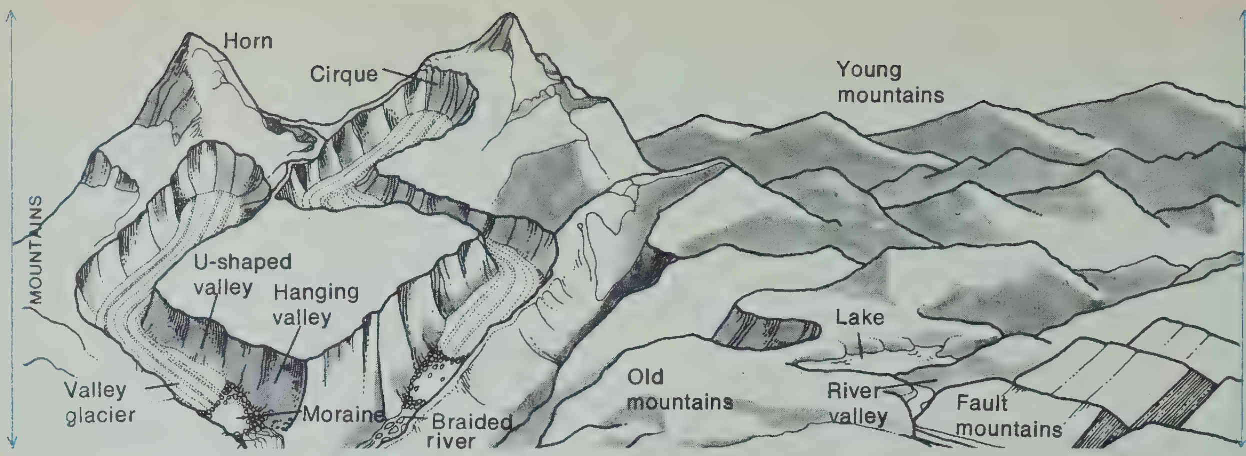


Figure 5-14

GET IT READY NOW FOR PART III

The biggest task is in setting up the stream tables. This involves preparing the supply buckets, making up the sand-silt combination, preparing sheets of plaster of paris, and procuring local-supply items. Items that must be procured locally are as follows: some bricks or wooden blocks to provide slope for the stream tables, large boxes or blocks to support the supply buckets, a wax marking pencil, chalk dust, 12 litres of sand, 1 litre of gravel, a cardboard carton, and paper, knife, and baby-food jars as used previously.

Two thin sheets of plaster are needed for each stream table to provide the hard cap-rock for the waterfall. The simplest way of preparing these sheets is to put a very thin layer of water into the bottom of a flat-bottomed rectangular or square dish. Sprinkle plaster of paris evenly into the water to make a wet layer about 3 mm deep. Allow this mixture to set. When it is almost set, cut through the plaster to make strips about 5 cm wide all the way across the dish. Allow these to set and dry completely.

Further information on materials preparation will be found in the text and in the introductory material in the front of this Teacher's Edition.

To find out how well you've done your work, look over Figure 5-14. You will recognize this drawing as part of the overview sketch you saw before in Figure 2-4. On the drawing, you will find examples of just about all the kinds of situations you've looked at in this chapter. If you've worked well, you should be able to give reasonable descriptions of the way each feature in the picture was formed. You should also be able to identify the forces acting upon each kind of mountain and to predict what changes these will produce in the future.

Before going on, do Self-Evaluation 5 in your Record Book.

Excursion 5-1
Snow to Ice

PURPOSE: To examine the process by which snow changes to ice.

EQUIPMENT

None

MAJOR POINTS

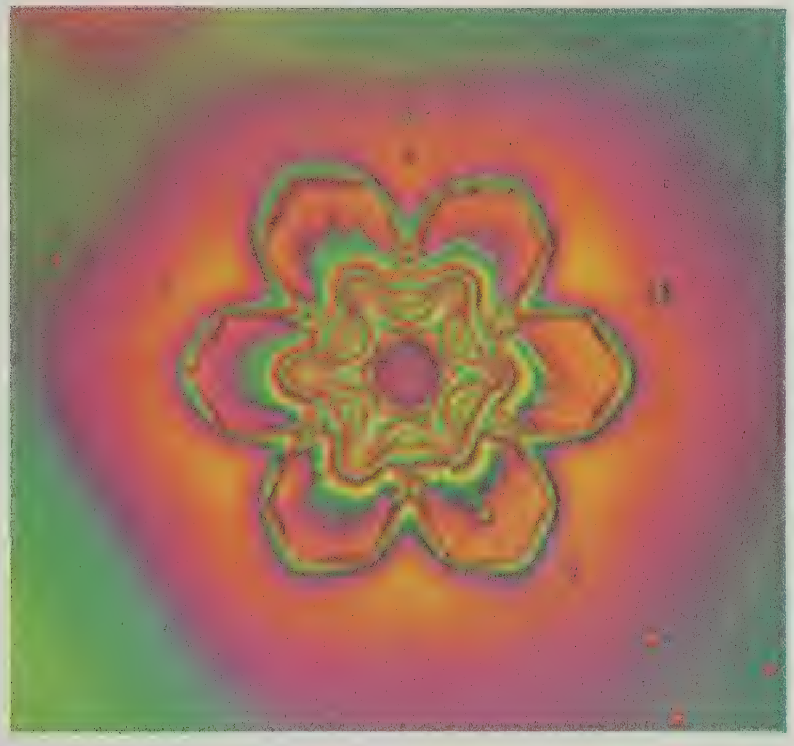
1. Snowflakes are always six-sided, with much open space in the crystals.
2. Pressure on accumulated snowflakes changes them to ice grains.
3. Further packing, pressure, and addition of water change the grains to solid ice.
4. The change from snow to solid ice can take as long as 300 years.

When snow changes to ice under pressure, its density changes dramatically. Snow has an average density about 0.1 that of water, although this figure may vary. The density of ice under normal pressure is about 0.9 that of water, or 9 times the average density of snow.

This excursion deals with the process by which snow turns into glacial ice.

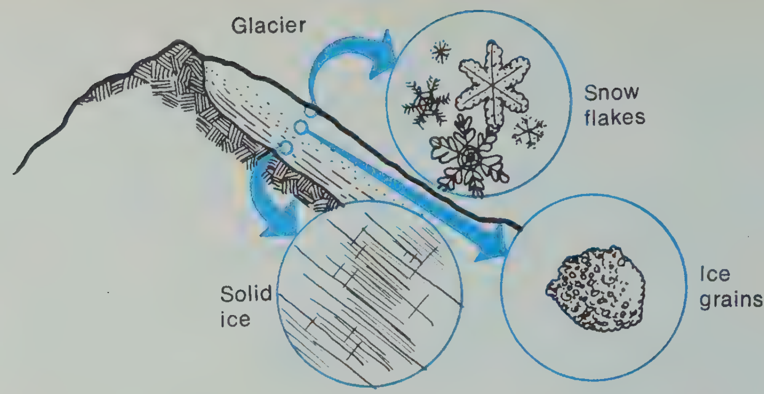
When snowflakes are examined closely, they are always seen to be six-sided (*hexagonal*). Because no two snowflakes are the same, there are millions of variations of this hexagonal form. In spite of their variety, however, all snowflakes are quite delicate, with lots of open space. For this reason, freshly fallen snow tends to be rather loose, light in weight, and not hard like ice.

Figure 1



At high elevations in the mountains, snowfall often exceeds the rate of melting. This results in peaks that remain snow-covered the year around. As snow accumulates, there is greater and greater pressure exerted on the snowflakes at the bottom of the pile. In time, the flakes lose their delicate structure and become loosely packed ice grains. This process may take approximately a year, depending upon the weather.

Figure 2



With further packing and the addition of water from melting snow, the granular ice may gradually turn to solid ice. At a depth of about 30 metres, the pressure is great enough to cause the particles to lose their granular form and fuse into solid ice. In cold climates, this change from snow to granular ice and, finally, to solid ice can take up to 300 years.

☐ **1.** Why is the top surface of a glacier much lighter than the bottom surface?

PART III

The Midlands

The Midlands A Pathway to The Sea

Excursion 6-1 is keyed to this chapter.

6

CHAPTER EMPHASIS

Erosion and deposition are major processes that shape the midland sector of North America. The principle agent of both processes is water flowing in rivers. Changes in the stream's hydraulic factors result in different effects on the landscape.

FILMSTRIP KEY

Techniques
Setting Up ▪ Stream Table

EQUIPMENT

Per student-team

1 stream table, complete with supply hose, exit hose, and screw clamps
1 supply bucket
2 regular buckets
Wooden block or brick
Support for supply bucket
1 dropper
1 wax pencil
Food coloring
Handful of gravel
Watch or clock, with second hand
Modeling clay
Sand-silt mixture

MAJOR POINTS

1. A large area of high elevation is located in the western U.S., with ▪ smaller area in the eastern U.S.
2. Most of the areas of low elevation are located in the eastern half of the country.
3. When elevations and river systems are examined together, rivers seem to originate generally in higher elevations and flow toward areas of lower elevation.
4. In general, river systems seem to flow in two patterns—in the eastern U.S. they flow toward the Atlantic Ocean or the Gulf of Mexico, and in the western U.S. they flow toward the Gulf of Mexico or the Pacific Ocean.
5. Simulation of different river systems is provided by using a stream table.
6. A systems approach is used in studying the effects of different variables. These are the conclusions drawn:
   a. Increasing the slope of the stream bed increases the rate of flow of water.
   b. Increasing the channel roughness decreases the flow of water.
   c. Increasing the water volume increases the rate of flow of water.

The entire United States does not have spectacular mountain peaks, crashing surf, or seacoast bathing beaches. Instead, much of it is covered by flat plains or gently rolling hills, cut through here and there by rivers. That describes most of the land known as the midlands. It is this midland area, between mountains and sea, that you will study in Part III.

Figure 6-1

Figure 6-1 is a section of Figure 2-4.

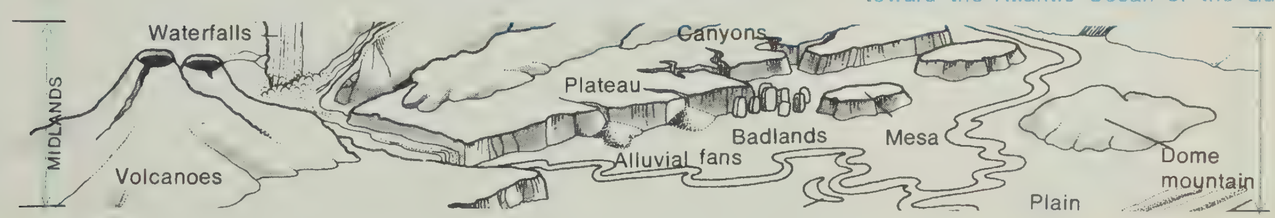


Figure 6-1 shows many important features of the midlands region. Features from many parts of the country have been combined into this one diagram. Figure 6-2 (on page 100) gives you some idea of how much land in the United States can be described as midlands.

Before going on, take a close look at the features shown in Figure 6-1. By the end of your study, you should be able to describe how the midland features were formed and to predict what the midlands might look like in the future.

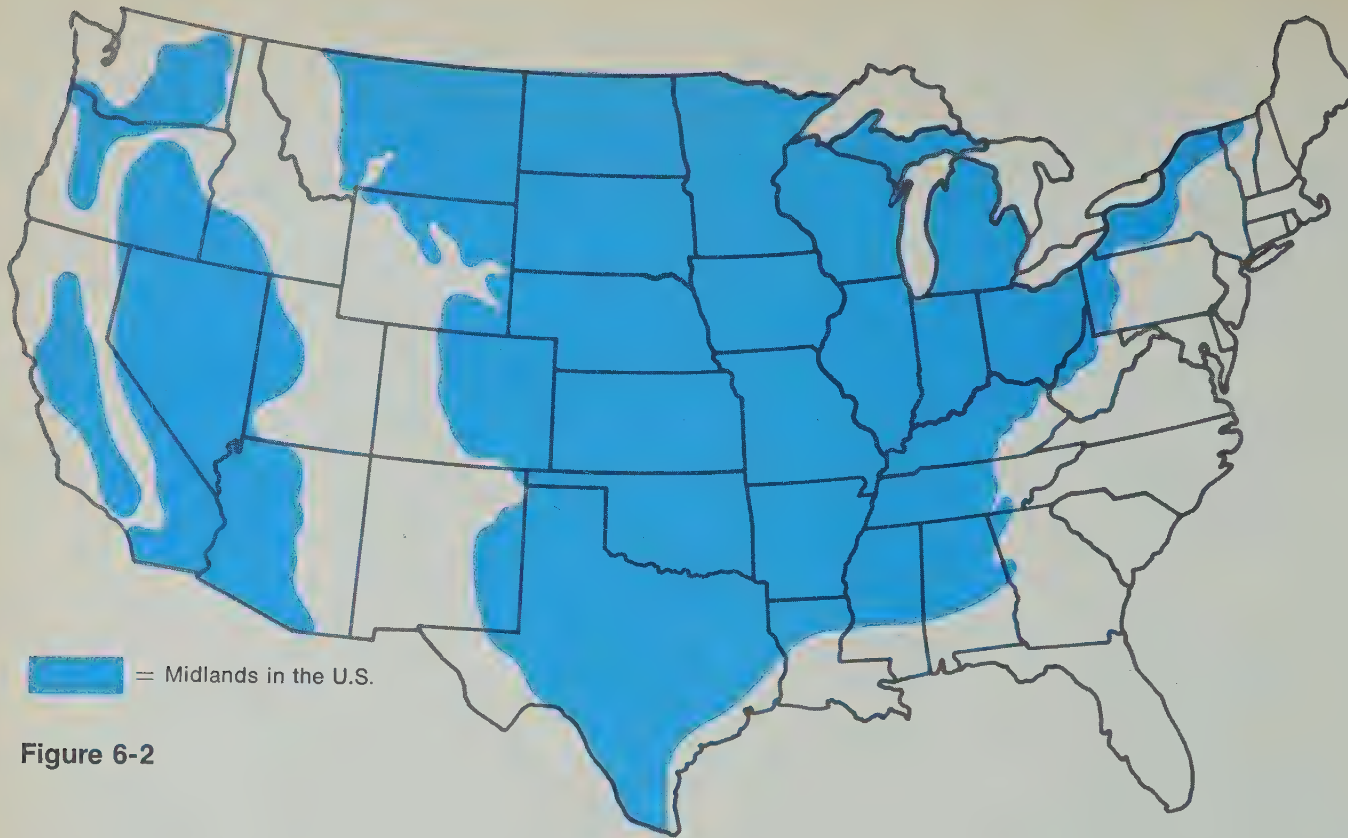


Figure 6-2

Figure 6-3

☐ **6-1.** Look at Figure 6-2. Which occupies the greater land area, the midlands or the remaining regions?

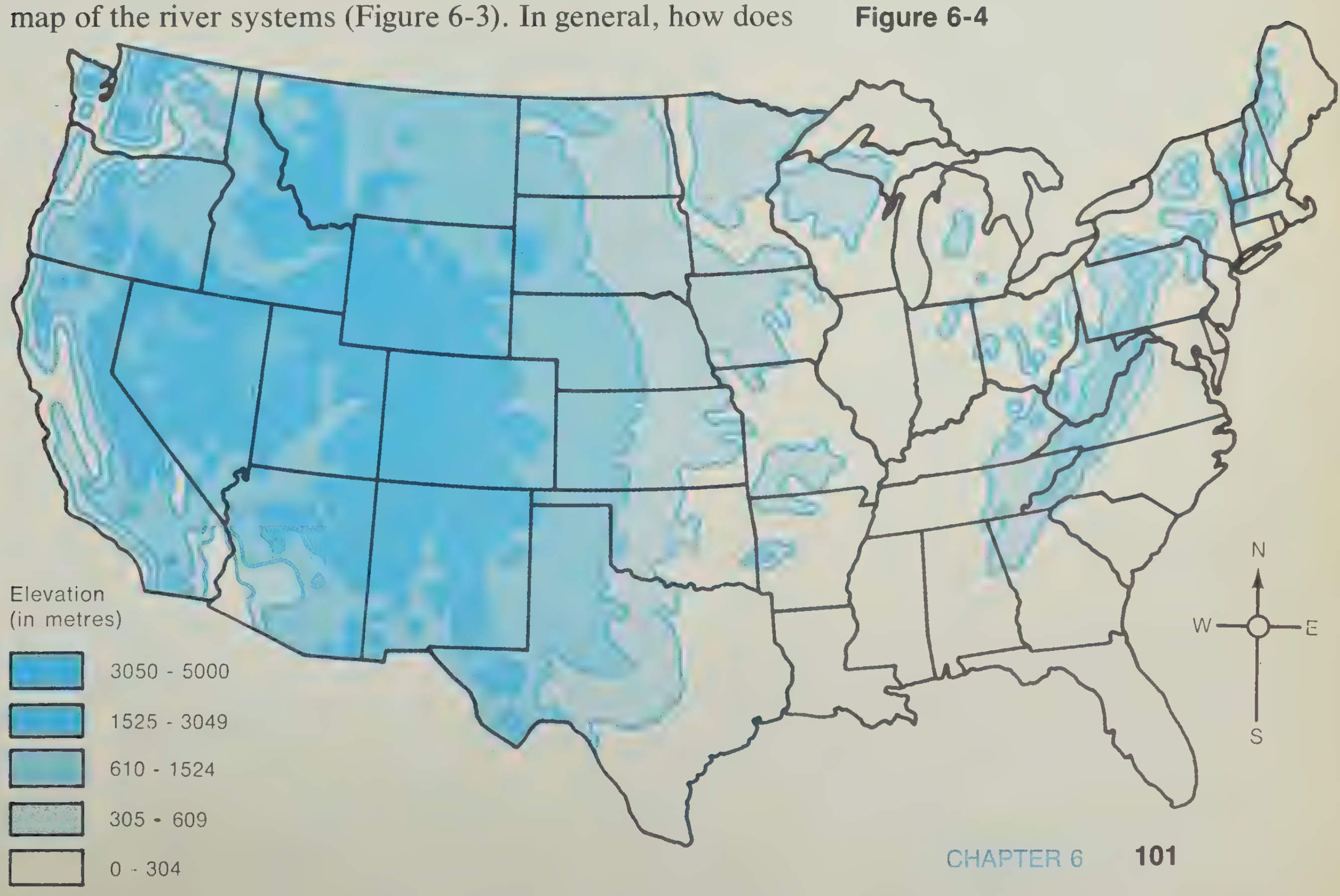
The midlands have been shaped largely by rivers. Figure 6-3 shows the major river systems of the United States. In general, the rivers seem to flow in two patterns. In the eastern United States, they flow either toward the Atlantic Ocean or the Gulf of Mexico. In the western United States, they flow east to the Mississippi and on to the Gulf of Mexico, or they flow toward the Pacific Ocean.

Almost all the rain that falls on the United States eventually flows out to sea through the river system. This happens because water flows from higher to lower elevations. Figure 6-4 shows the general elevations of the United States.

☐ **6-2.** Which has more areas of high elevation, the eastern or western United States?

☐ **6-3.** Compare the elevation map (Figure 6-4) with the map of the river systems (Figure 6-3). In general, how does

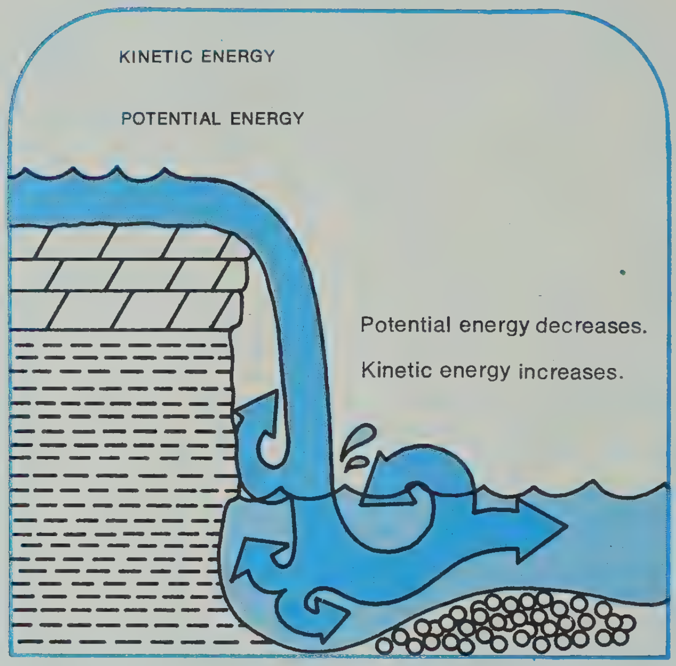
Figure 6-4



the elevation where rivers originate compare with the elevation downstream?

☐ **6-4.** Compare the elevation map (Figure 6-4) with the map of the midlands (Figure 6-2). Do the midlands all have the same general elevation?

Figure 6-5



Rivers generally originate at high elevations. And they always flow to points of lower elevation. It is the energy of this flowing water that shapes the landscape of the midlands.

When an object falls, it loses *potential energy*. At the same time, it picks up speed and gains *kinetic energy*. The water in a river that starts high in the mountains behaves much like any falling object, as it flows to the sea.

☐ **6-5.** When does a river have its greatest kinetic energy? When does it have its greatest potential energy?

Take a look at Figure 6-6. The water at the top of DeSoto Falls in Alabama has kinetic energy of the sort just discussed. But it also has a great deal of potential energy because of its height—well above the base of the falls. As the water plunges over the falls, its kinetic energy increases. At the same time, its potential energy decreases. When the water reaches the bottom of the falls, it crashes into the rocks and slows down again. Figure 6-5 summarizes these changes in energy.

☐ **6-6.** What makes the water slow down at the base of the falls?

THE STREAM TABLE

In order to study the work of rivers in the classroom, it will be necessary for you to use a stream table. In order to do many of your activities, you will set up an artificial stream, using the table.

One of the problems in interpreting the natural landscape is that many important variables act at the same time. The stream table will allow you to control some of the important variables that are uncontrollable in nature. For example, you'll be able to do such things as create a river, speed it up or slow it down, or make it flow through different types of material that you select. These possibilities can help greatly in describing how real rivers behave on their pathway to the sea.

Figure 6-6

Energy conversions (potential to kinetic, etc.) are made when work is done. The water with high kinetic energy does work on the rocks at the bottom of the falls. Whenever energy is changed from one form to another some of it is changed to heat due to friction. Little noticeable temperature increase would be measured at the bottom of ■ falls, however, because of the cooling effects of evaporation and other factors.

The standard setup is similar for all stream-table experiments. Take a careful look at Figure 6-7 and notice the parts that are used.

The supply bucket should be elevated on blocks or a box about 30 cm above the table. If a cardboard box is used, be sure that it is strong enough to support the pail of water (about 5 kg). A plastic cover will provide protection from sloshing water.

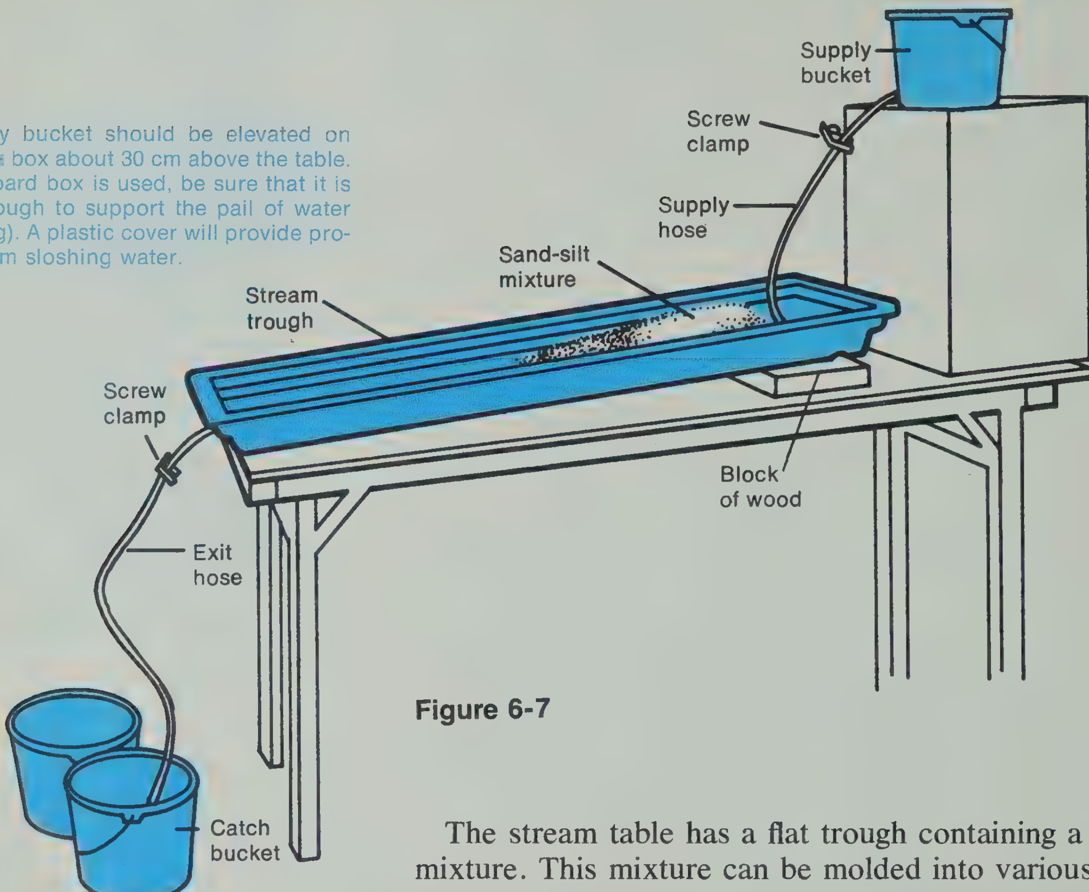
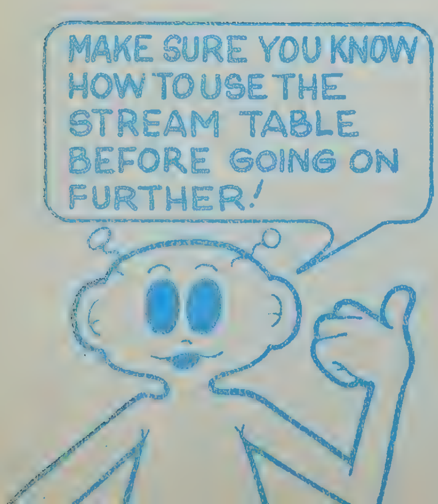


Figure 6-7

The stream table has a flat trough containing a sand-silt mixture. This mixture can be molded into various shapes. Water comes from an elevated bucket, through a supply hose, and flows across the sand-silt mixture in the trough. It leaves the other end through an exit hose that leads to a catch bucket. The flow of water in and out can be controlled by opening and closing screw clamps. The slope can be changed by moving a support (such as a brick or a wooden block) back and forth under the trough.



You will use your stream table to study such things as the following.

1. Rate of flow in a stream
2. Rate of flow leaving a lake
3. Making a reservoir
4. Slope of a stream

Before you study these things, you should practice using your stream table, as described below.

1. *To Control the Rate of Flow from the Supply Bucket*

Most of the stream-table experiments call for you to adjust the rate of flow of water into the trough. Doing this is easy. But first you have to know how to measure volume in millilitres. If you don't, look over **Resource 2,** "More Metric Measures," in your Resource Book. After that, all you do is simply time how long it takes (in seconds) for the supply hose to fill a 100-ml graduated beaker. You can then calculate the rate of flow like this: Say it takes five seconds to fill the beaker. Then the rate of flow is as follows:

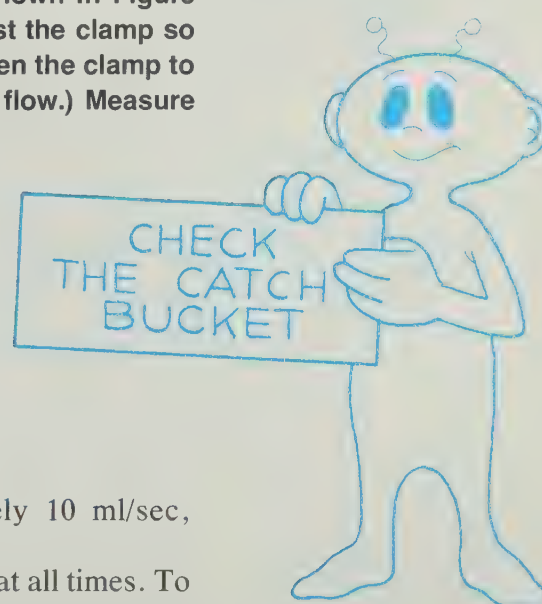
Note that some kind of timing device must be available for timing the flow in seconds. If your room has a clock with a sweep-second hand, it will work fine. Students may have their own watches that can be read in seconds.

Rate of flow will be somewhat dependent on how full the supply bucket is. More frequent replenishing will maintain a more uniform level and result in a more constant rate of flow.

$$\frac{100 \text{ ml (volume of water)}}{5 \text{ sec (time)}} = 20 \text{ ml/sec (rate of flow)}$$

ACTIVITY 6-1. Set up the stream table as shown in Figure 6-7. Pour water into the supply bucket. Adjust the clamp so that you get a rate of flow of 10 ml/sec. (Tighten the clamp to reduce the flow, and open it to increase the flow.) Measure the rate of flow as described above.

Rate-of-flow values are approximate and can be varied up or down by 2 ml/sec. Thus, any rate from 8 ml/sec to 12 ml/sec will do when 10 ml/sec is asked for.



When you have a flow of approximately 10 ml/sec, change the flow to 5 ml/sec.

You must keep water in the supply bucket at all times. To help you do this, an extra bucket has been supplied. When you see the supply bucket becoming empty, replace the full catch bucket with the extra bucket. Then transfer the water to the supply bucket. You will probably have to do this every 5 minutes or so.

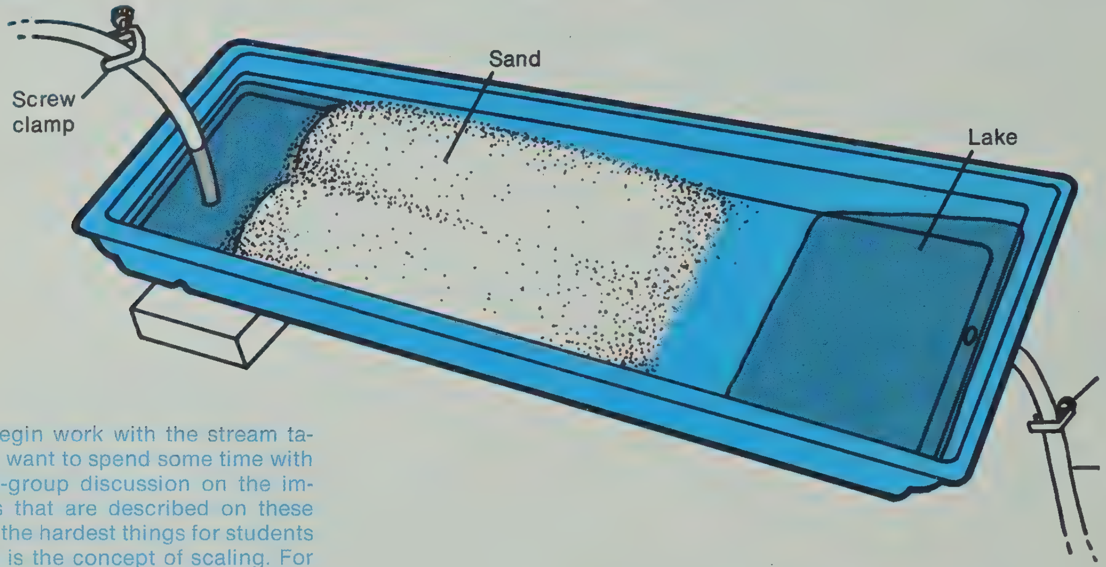
Caution *Watch the catch bucket. Don't let it overflow!*

2. *To Control the Flow of Water Leaving the Trough*

Some activities ask you to form a lake at the bottom of the trough. You can control the formation and depth of such a lake by adjusting the screw clamp on the exit hose. (If you change the amount of water entering the trough, the lake level will also change unless you readjust the exit hose screw clamp.)

To create a lake, the exit flow must be less than the entry flow.

ACTIVITY 6-2. With the water flowing in at 5 ml/sec, adjust the exit hose to create a lake.



As students begin work with the stream table, you might want to spend some time with them in small-group discussion on the important points that are described on these pages. One of the hardest things for students to understand is the concept of scaling. For example, suppose a river is simulated by a flow of water 1 cm wide in the stream table. This might represent a width of 20 m in the actual river. The ratio of 1 cm to 20 m is 1 to 2000. If everything else in the stream table were at the same scale, then a tiny grain of sand 0.25 mm in diameter would represent a rock 2000 times as large, or 50 cm across. Yet the speed at which the real river flows would not be 2000 times greater than the speed of the water in the stream table. So the activities only serve as a rather rough approximation of the actual events and features.

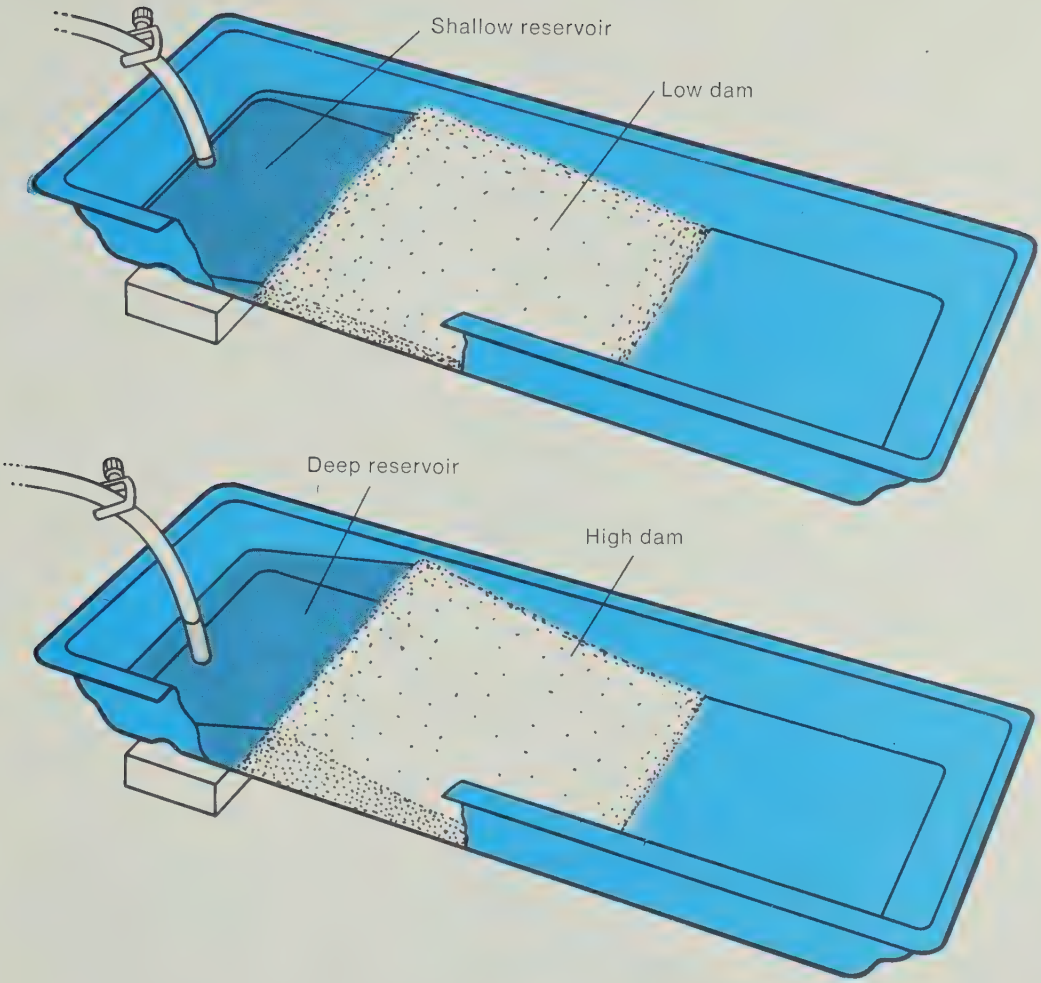
3. *To Make a Reservoir*

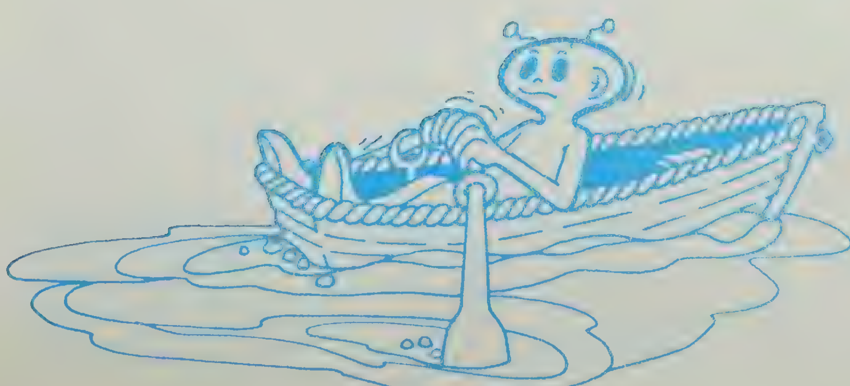
Some activities call for a reservoir at the upper end of the trough. To make a reservoir, pile up a thick layer of sand and silt near the top of the trough. Pile up the sand-and-silt with your hands or use a small board. Figure 6-8 shows where and how to do this. You can make the reservoir deeper by making the sand and silt layer thicker.

4. *To Adjust the Slope of the Trough*

Most activities call for you to raise the upper end of the trough a certain number of centimetres above the table. To do this, simply slip a support under the trough. Then move the support back and forth to get the right height.

Figure 6-8





THINGS TO WATCH FOR

Some teachers have found that a sign saying "Check the catch bucket" posted near the stream table is a helpful reminder to guard against overflow and the resulting mess.

1. Watch the catch bucket. You must keep your eye on the catch bucket to keep it from overflowing. You can avoid the problem in some activities by pouring less than a full bucket of water into the supply system to start with. Any time you use more than one full bucket of water, you will need a third bucket to trade positions with the catch bucket before it's too late.
2. Be sure that the water-supply pail is set on a box or other support about 30 cm above the table.
3. Keep the supply hose and clamp attached at all times to control the water flow.
4. Do not remove the sand-silt mixture from the trough when you finish an experiment. The next person using the table will need the same material.
5. The stream table isn't a perfect model. You will not get exactly the same effects that a real river would produce.

THE SPEED OF A RIVER

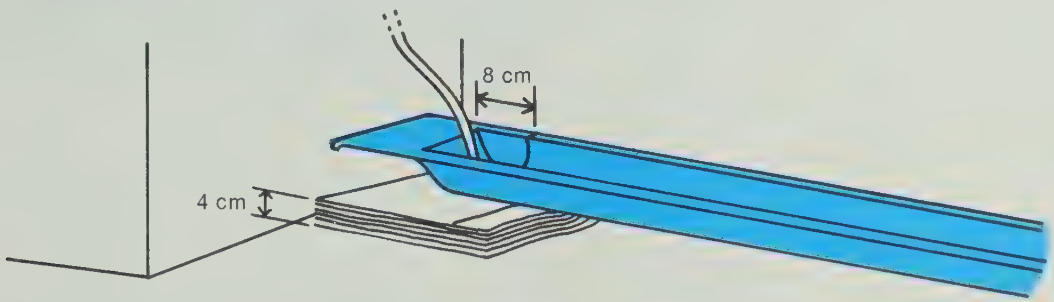
Many rivers begin in the mountains. Some of them come from glaciers. Figure 6-9 shows two different views of a river. In the picture on the right, the water is flowing swiftly, and there are many rapids in the stream channel. In the picture on the left, the river is sluggish, with no rapids, and the surrounding land is very flat.

Figure 6-9

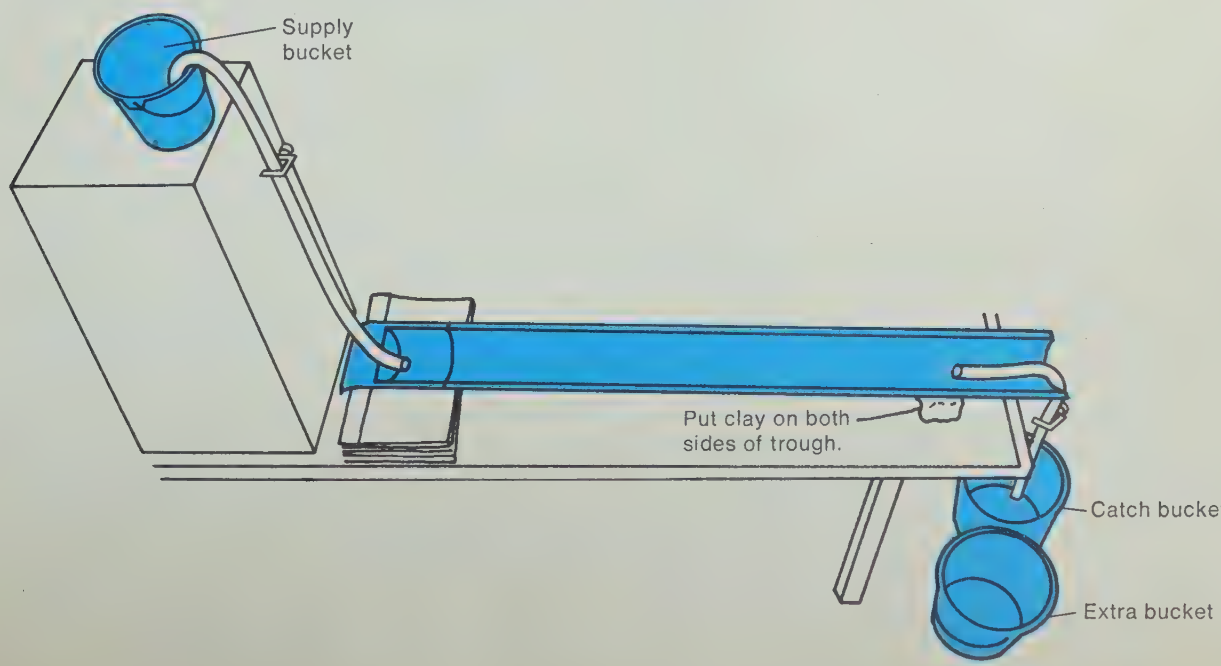
You can determine what variables affect the speed at which water flows. To do the experiments, you will need a partner and this equipment:

1 stream table	Handful of gravel
1 dropper	Modeling clay
1 wax pencil	Metric ruler
1 water-supply system for the stream table	Watch or clock, with second hand
Food coloring	Sand-silt mixture

ACTIVITY 6-3. With a wax pencil, mark a starting line 8 cm from the upper end of the trough. Elevate the upper end of the trough 4 cm.



ACTIVITY 6-4. Set up the water-supply system as shown. Add some sand-silt mixture. Adjust the water flow into the trough to 10 ml/sec. Keep the supply bucket at least half full of water at all times. Do not let the catch bucket overflow!



Some students may wonder why food coloring is used to measure speed in this activity, whereas in Activity 6-1, rate of flow was determined by measuring the time required to fill a 100-ml beaker. The reason for this difference in technique is that two different quantities are being measured. In Activity 6-1, the quantity measured is rate of flow from the supply bucket. This is a volumetric quantity. It is related to—but not always indicative of—the speed of a stream. The same volume flow of water can result in different stream speeds, depending on the depth of the stream and other factors. It is the speed of the stream that is measured in Activity 6-5.

ACTIVITY 6-5. Add a drop of food coloring to the water as it flows past the starting line. Time how long it takes the dye to reach the end of the trough. Calculate the speed in centimetres per second. (Speed = distance traveled ÷ time) Record your data under Trial 1 in Table 6-1 of your Record Book.

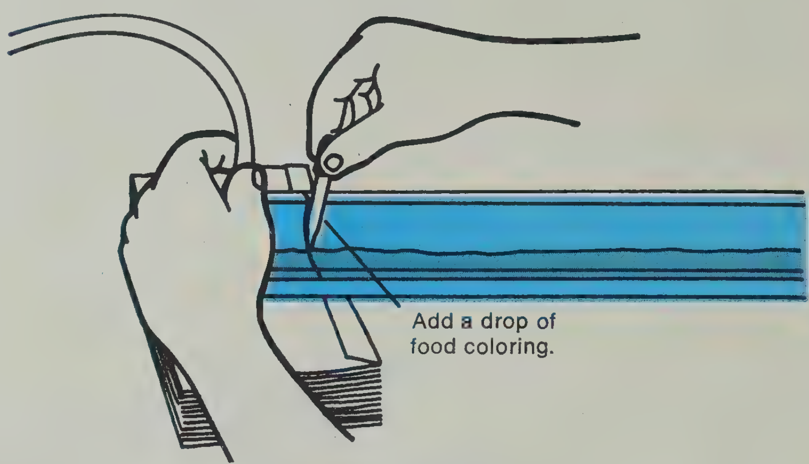


Table 6-1

	Slope (in cm)	Rate of flow into trough (in ml/sec)	Trough bed	Speed (in cm/sec)
Trial 1	4	10	Sand-silt	
Trial 2	8	10	Sand-silt	
Trial 3	12	10	Sand-silt	
Trial 4	4	20	Sand-silt	
Trial 5	4	10	Gravel over sand-silt	

The amount of gravel used in Trial 5 may vary, but it should be sufficient to have a noticeable effect on the flow in the stream trough. The gravel should be removed at the conclusion of the trial. Probably the best method of removing the gravel from the wet sand is to pick the individual pebbles out by hand.

Next, you will carefully and regularly change the slope of the trough, the amount of water flowing through the trough, and the bed over which the water flows. You will then decide whether or not changing these variables affects the rate of flow down the trough.

Set up and carry out Trials 2 through 5 as described in Table 6-1. (Note that Trial 5 calls for you to spread a layer of gravel along the stream bed.) Measure the rate of flow down the trough for each trial. Enter your results in the table in your Record Book. Notice that increasing the rate of flow increases the volume of water in the trough.

☐ **6-7.** What three variables affect how fast water flows down the trough?

If you did your work carefully, your results should agree with the following natural events. Rivers flow faster

(1) on steep slopes,
(2) when swollen by rains or melting snow, or
(3) when flowing over beds with few obstacles.

☐ **6-8.** What happens to the kinetic energy of river water as it travels over a steep slope?

☐ **6-9.** What happens to the kinetic energy of river water as it encounters gravel or rocks?

If you are interested in studying the effects of different obstacles in a river's path, do **Excursion 6-1**.

EXCURSION

Before going on, do Self-Evaluation 6 in your Record Book.

Excursion 6-1

Effects of Obstacles upon Direction of Stream Flow

EQUIPMENT

None

PURPOSE

To examine causes for stream braiding.

MAJOR POINTS

1. The stream itself often drops obstacles in its bed.
2. These obstacles cause the stream to divide into more than one channel.

In this excursion, you will study photographs of rivers flowing over several kinds of materials. Your problem will be to note and try to explain any changes in a river's course as a result of obstacles it encounters.

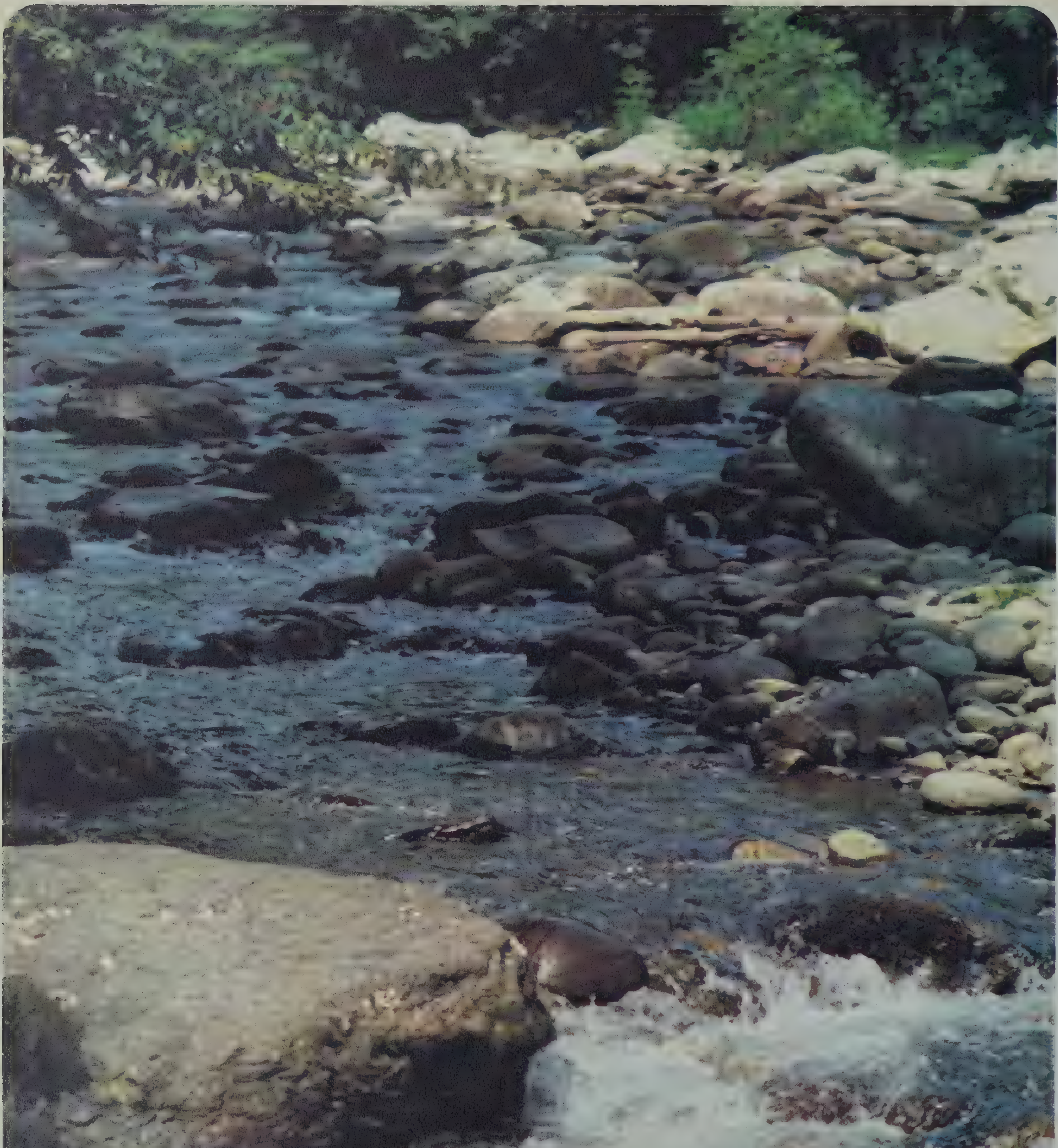
First, take a look at Figure 1. Notice that the river is flowing through an area of sand deposits. As the river flows around some of the sand "islands," it is broken up into a series of small streams. (This is called *braiding*.)

Figure 1

Take another look at Figure 1. Notice that the sand deposits that cause the braiding are located where the land begins to level off. The sand is carried down from the mountains by the river. Then, when the land flattens out, the river loses speed (kinetic energy), and it drops the sand particles. It is at points like this that one most often finds braided streams.

☐ **1.** The river in Figure 2 is braided, too. What caused the splitting this time?

Figure 2



Water at Work

7

Excursions 7-1 through 7-5 are keyed to this chapter.

CHAPTER EMPHASIS

In this chapter, the relationship between rate of stream flow and particle-carrying capacity is investigated.

FILMSTRIP KEY

Enrichment
Erosion and the Hydrologic Cycle
Weathering and Soils

EQUIPMENT

1 complete stream table
2 sheets of plaster, about 5 cm x 10 cm x 0.3 cm
Chalk dust
Wood splint
Sand–silt mixture

MAJOR POINTS

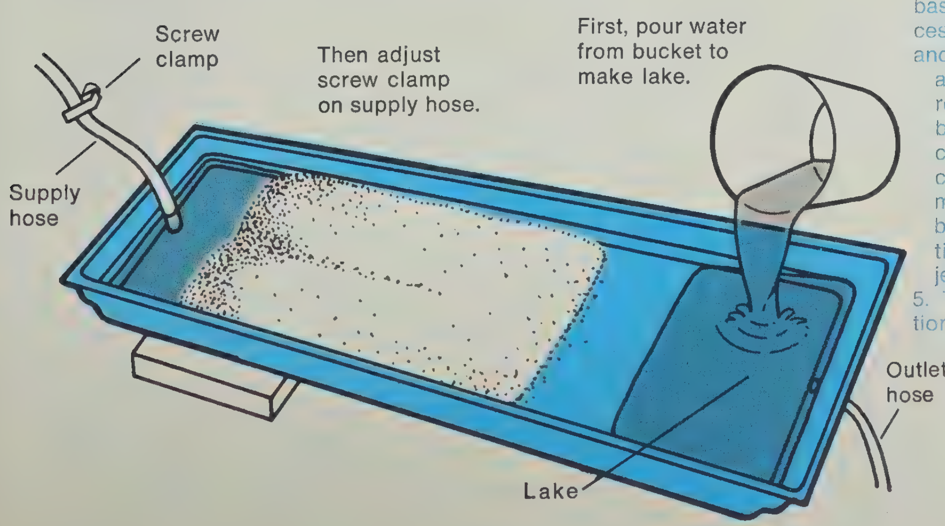
1. Particle-carrying capacity is a function of the river's kinetic energy and tends to increase as kinetic energy increases.
2. Deposition of sediment occurs when the kinetic energy of the river is below its particle-carrying capacity. Larger particles are deposited first, as the kinetic energy starts to decrease. Alluvial fans and deltas are examples of the last stage of this process, when the finest particles are deposited.
3. Stream-table studies show the following about potential and kinetic energy in river systems.
   a. The potential energy of a river is converted to kinetic energy as soon as water begins either to flow in a riverbed or to plunge over a falls.
   b. The kinetic energy of the river does work on the landscape; i.e., it erodes the land.
   c. Rivers generally originate in high-potential-energy regions, such as mountain areas.
4. Predictions about geologic features are based on knowledge of the interaction processes. More specifically, the student makes and tests the following predictions.
   a. Waterfalls occur where more-resistant rock intersects the stream profile.
   b. Gullies erode the landscape by a process of headward erosion.
   c. The kinetic energy of a river with a meandering path is greater on the outside bend. Erosion of the riverbank is differential, with the outside bends being subjected to more erosion than the inside.
5. The process of wind erosion and deposition produces features such as sand dunes.

How large a rock can a stream carry along? Depends upon the stream, you say? It is pretty obvious that the fastest moving streams have the greatest kinetic energy and, therefore can carry the largest rocks. But streams do not have a constant rate of flow—they speed up and slow down many times over their courses. What happens to the materials being carried by a river when its rate of flow changes?

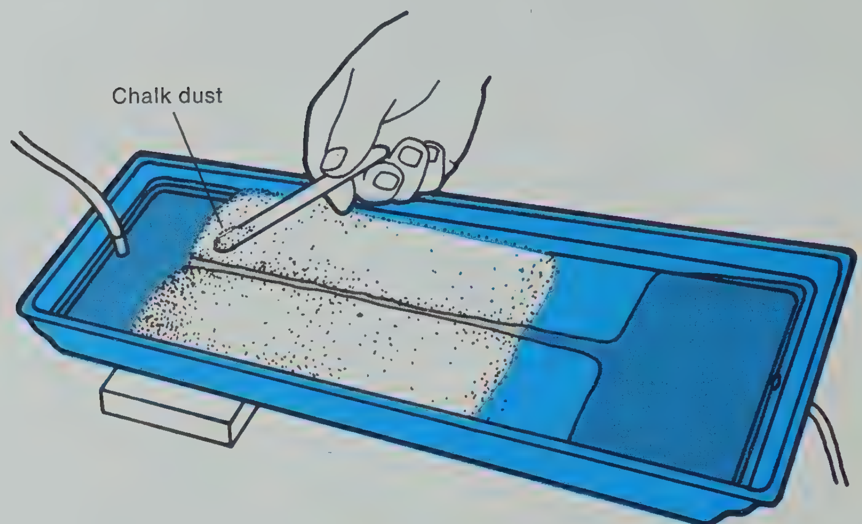
To find out, you will need the following materials:

1 complete stream table
Sand–silt mixture
Chalk dust
1 wood splint

ACTIVITY 7–1. Set up the stream table as shown. Pour enough water from a bucket to make a lake. Stop pouring when water just starts to flow through the outlet hose. Then adjust the inlet water flow to 3-5 ml /sec.



ACTIVITY 7-2. Put some chalk dust on a wood splint. Shake a few particles into the water as shown. Observe the particles and note the places where the stream's rate of flow changes. Note also where particles of sand and silt are deposited by the stream.



It is important to emphasize that, although sand moves rather rapidly in the stream table, in an actual meandering river it may take thousands of years for a grain of silt or sand to move from mountain peak to seashore. It makes the journey in a series of short hops. For several days it may be swept downstream and then lodge itself in a bank or backflow, where it remains for many years before making the next short journey.

If you did your work well, you should have found a relationship between the number and size of sand particles dropped by the stream and the changes in the stream's rate of flow.

☐ **7-1.** As the stream slows down (loses kinetic energy), what happens to the materials it carries?

☐ **7-2.** As the stream speeds up (gains kinetic energy), what happens to the amount of material it carries?

This general process works in nature as well as with the stream table. As a stream loses kinetic energy, it drops part of its load; as it gains kinetic energy, it picks up additional material.

☐ **7-3.** Take a look at Figure 7-1. Where would the stream be moving rapidly? Where would it be moving slowly?

Figure 7-1

WATERFALL FORMATION

Figure 7-2 shows a waterfall tumbling over a ledge of rock. Can you guess how the hardness of the rock at the top of the waterfall differs from the hardness of the rock at the bottom?

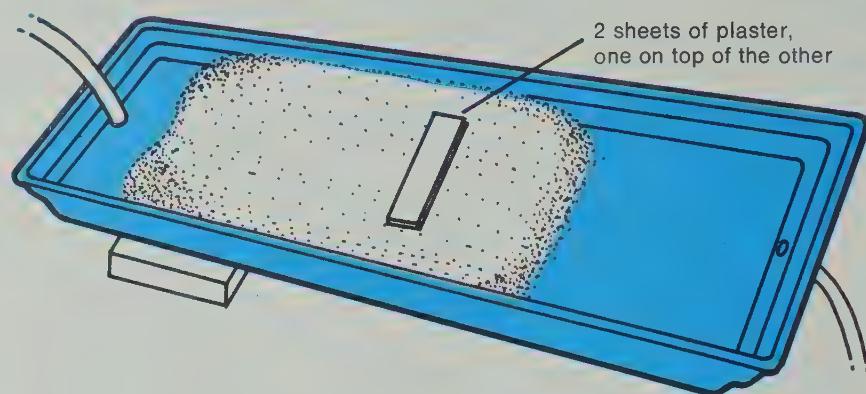
With your stream table, you can test the effect of relative hardness. You will then be able to work out a model for the process taking place. To do the activities that follow, you will need a partner and the following materials:

1 complete stream table
2 sheets of plaster, about 0.3 cm by 5 cm by 10 cm

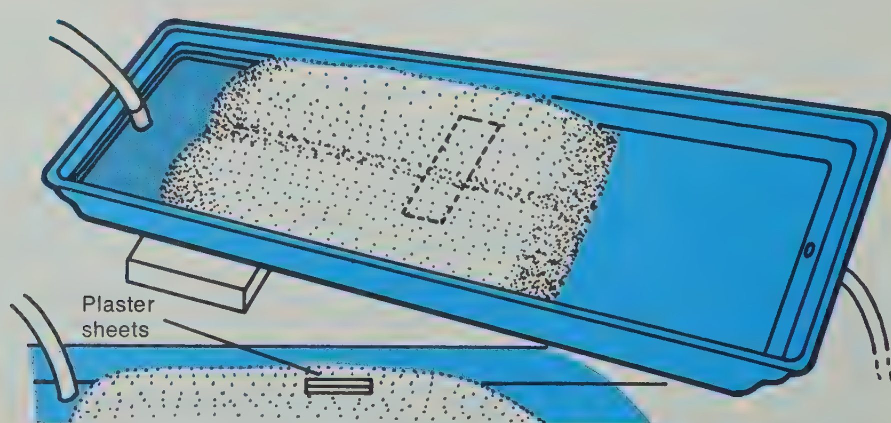
Figure 7-2

The preparation of the plaster sheets, which represent a hard-rock layer, is described in the teacher's notes at the end of Chapter 5.

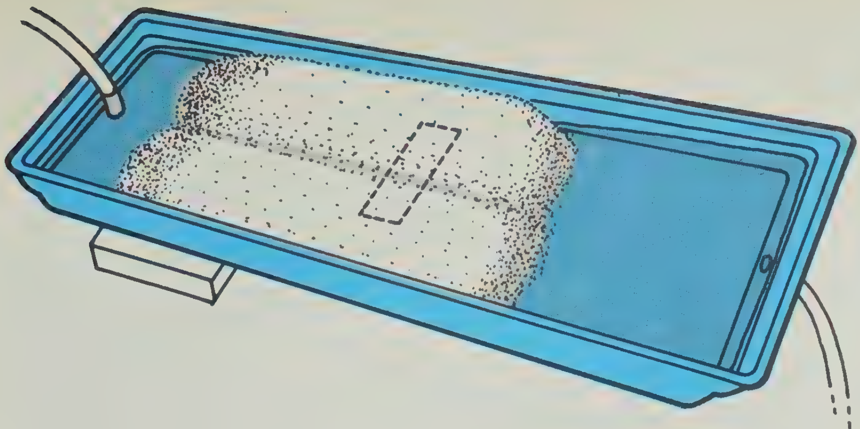
ACTIVITY 7-3. Set up the stream table and sand mixture as shown. Make a layer of sand-silt mixture about 3 cm deep. Place two sheets of thin plaster on the layer as shown.



ACTIVITY 7-4. Now cover the plaster with a layer of sand. Make a slight groove, or valley, along the length of the sand, as shown. This will make the stream flow directly above the buried plaster. Start the water flowing.



ACTIVITY 7-5. Adjust the water flow into the reservoir to 5 ml/sec. Let the water run down the valley until it has eroded enough sand to uncover the plaster. Allow erosion to continue for about 5 minutes after the plaster is uncovered.



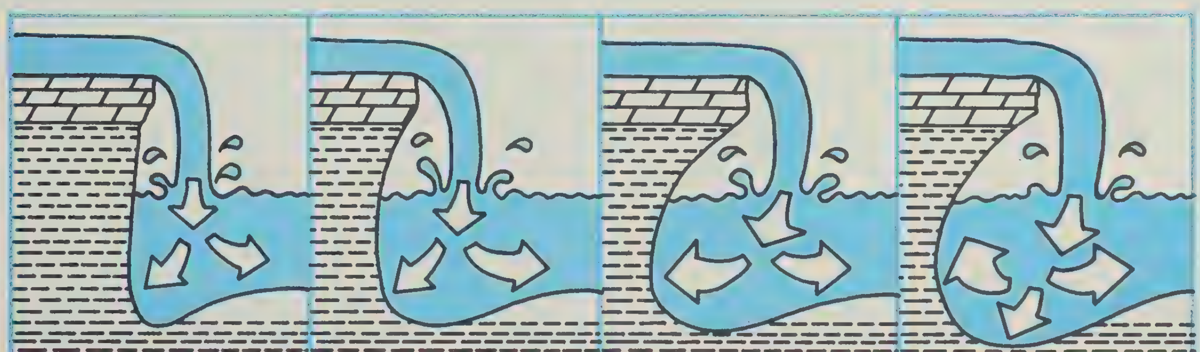
If the water is allowed to flow for a long enough time, the stream will undercut the plaster sheets. If a wide stream were used, it might be possible to undercut enough to cause the plaster sheets to collapse, modeling the action of a falls cutting its way up a stream.

The plaster represents a layer of igneous rock or perhaps hard sedimentary rock. The sand-silt mixture represents softer rock above and below the harder rock.

☐ **7-4.** When the plaster becomes exposed, what happens to the rate of erosion upstream and downstream from it?

Now take a look at Figure 7-3. It diagrams the effects of water flowing over a falls like the one you just built. Notice the deep, rounded area at the bottom. It is called a *pothole*. Potholes often make excellent fishing and swimming holes.

Figure 7-3



Waterfalls are common landscape features where water flows rapidly over a hard rock ledge. When the ledge rests on softer rock, the water will erode the softer rock faster than the top layer, resulting in a sharp edge to the falls as shown in Figure 7-3.

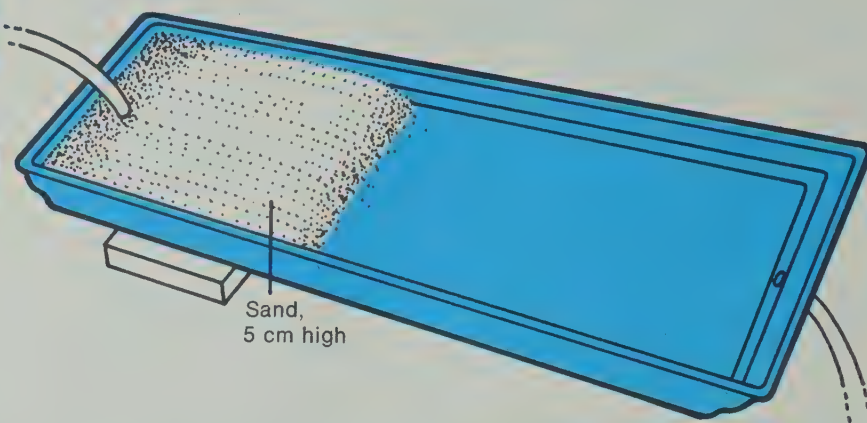
☐ **7-5.** If you have done Part II, on mountains, you should be able to make a good guess as to which rock type is at the

top of a waterfall. Would it be igneous, metamorphic, or sedimentary?

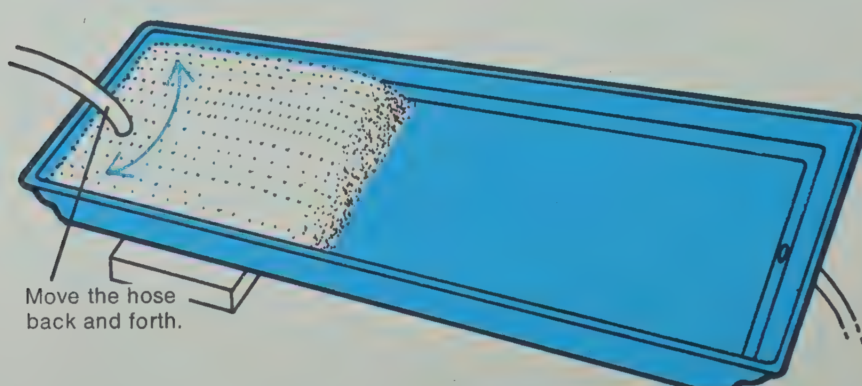
GULLYING AND EROSION

Running water does not always flow over hard materials and create beautiful waterfalls. For example, what happens when water runs off a flat-topped hill? To find out, you will need a complete stream table and the help of a partner.

ACTIVITY 7-6. Set up your apparatus as shown. Be sure that the flat-topped hill of sand is at least 5 cm high.



ACTIVITY 7-7. Adjust the rate of water flow to less than 3 ml/sec. Move the hose back and forth so the water falls on different parts of the hill. Observe what happens.



☐ **7-6.** What happens to the sand as water runs off the hill?

☐ **7-7.** Why do gullies begin to form?

Figure 7-4

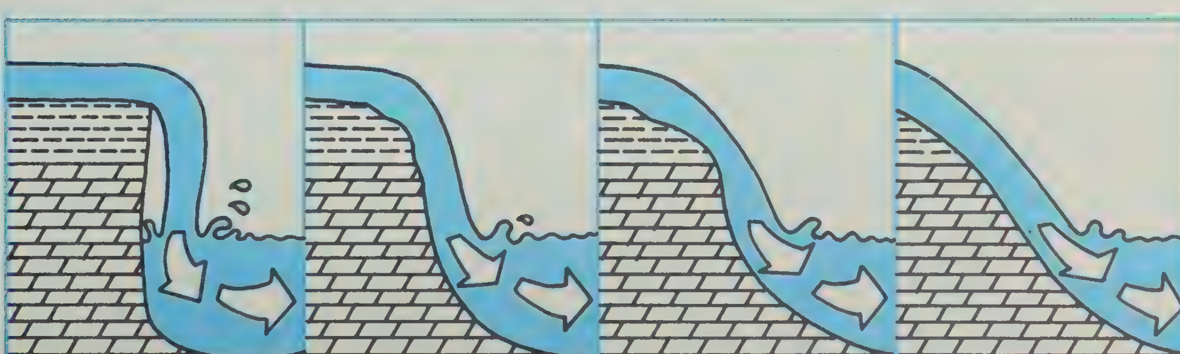
Figure 7-4 shows the effects of water running off a hill of fairly loose material. At one time, the area probably contained only a single gully. As water flowed into the main gully from the sides, other gullies formed.

Sometimes waterfalls are formed at the tops of gullies. During rainstorms, the water that pours over these falls gradually erodes away the lip of the gully. In this way, gullies become longer and longer. This process is known as *headward erosion*. This is diagrammed in Figure 7-5.

What's the difference between a gully and a canyon? Will the area in Figure 7-4 ever be a canyon? If you would like to know more about this, do **Excursion 7-1**, ''Gullies and Canyons—A Comparison.''

EXCURSION

Figure 7-5



Waterfalls also have headward erosion. Look at Figures 7-6 and 7-7. They show two views of Niagara Falls in New York State. The top of these falls is a flat plain with gently rolling hills. The falls are more than 50 metres high. Each year the falls cut back into the plain about 1.5 metres. During the last thousand years, the brink of the falls has moved back about 1500 metres. This has resulted in the long canyon that the falls crash into today.

☐ **7-8.** How much headward erosion occurs with Niagara Falls each year?

Figure 7-6

☐ **7-9.** Why does so much broken rock collect at the base of the falls?

In this chapter you have seen that fast-moving water cuts away the surfaces over which it flows. Some of the heavier pieces don't move downstream very far until they are worn or broken down to smaller size. Then they are carried farther downstream. But where do they end up? What kind of formations do they make?

☐ **7-10.** What happens to the load of particles being carried downstream as the water slows down? (Hint: See your results in Activity 7-2.)

☐ **7-11.** What factors cause streams of water to slow down?

Figure 7-7

Figure 7-8

Typically a river or stream slows down when it reaches a bend, when it gets wider, or when its slope decreases. Figures 7-8, 7-9, and 7-10 show the formation that occurs in each case.

EXCURSION

Figure 7-8 shows the sand buildup that occurs on the inside turn of the river. You can see how this happens if you do **Excursion 7-2**, ''Action of Water Moving in a Curved Path.''

☐ **7-12.** Look at Figure 7-8. What evidence is there that the water flows faster on the outside of the turn?

☐ **7-13.** Which side of the river is being eroded more? Where do you think this eroded material is going?

Figure 7-9 is a satellite view of the Mississippi River delta. A *delta* is new land that develops at the mouth of a river, where large amounts of sand and silt are deposited. The Mississippi drops 2 million metric tons of sand and silt a day into the Gulf of Mexico. No wonder a delta forms!

This has been going on for such a long time that the sediment is now estimated to be about 10 000 m deep at the river's delta. The weight of all this material is so great that it causes the earth's crust to sag about 1 m every 100 years. The sagging will probably cause some adjustments in the distant future; uplift may occur in lands surrounding the Gulf.

☐ **7-14.** Why do such formations occur only at the mouth of streams or rivers?

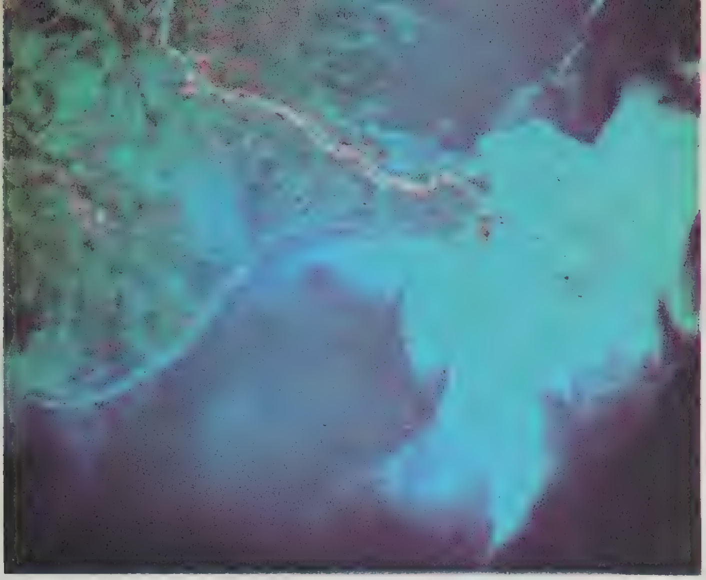


Figure 7-9

Figure 7-10

A delta forms when a stream or river flows into a wide body of water such as an ocean or a lake. When river water flows into such a large body of water, it abruptly slows down. As a result, it drops most of its load of sand and silt. Using the stream table, you can form your own delta. **Excursion 7-3**, ''Delta Formation and Changes in Sea Level,'' suggests how to do it.

EXCURSION

Figure 7-10 shows something you can find at the foot of almost any little gully. It is called an *alluvial fan*. Alluvial fans are somewhat like deltas except that they are found at the bottom of steep slopes.

☐ **7-15.** In what way is a stream as it reaches the foot of a slope similar to a river as it meets the sea?

Factors such as steepness of slope, looseness of material, and the rate and amount of water flowing all affect what alluvial fans actually look like. Using **Excursion 7-4**, ''Alluvial Fan Formation,'' you can design your own experiment to find out how this is so.

EXCURSION

OTHER FORCES THAT SHAPE THE MIDLANDS

It is obvious that water has a good deal to do with shaping the landscape. In some places it adds land, and in others it wears away land. But other forces are also important in forming the midlands. Let's look at one of these.

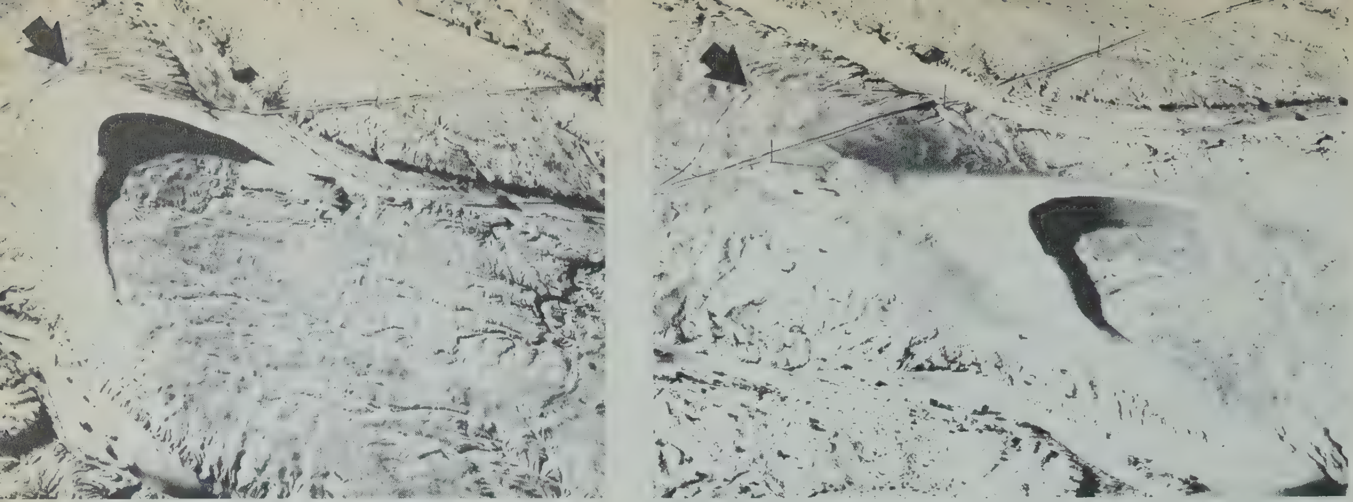


Figure 7-11

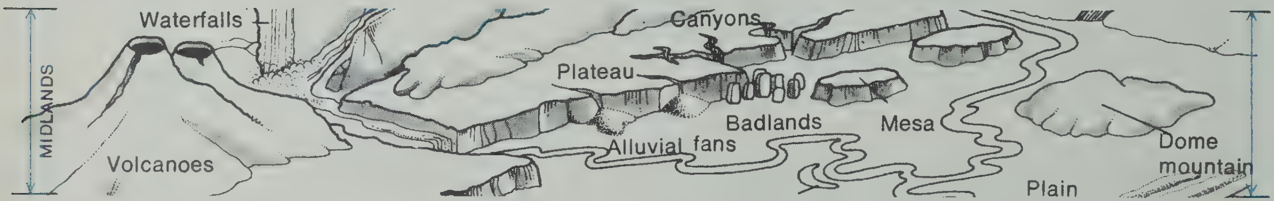
The sand has moved from left to right. The left photograph was taken first.

The two photographs in Figure 7-11 were taken seven years apart. Wind caused the motion of the sand dune that you see. The arrows point to the same location in both pictures.

Based on evidence in the photographs, in what direction do you think the sand has moved? Which photograph do you think was taken first? **Excursion 7-5**, "Dunes on the Move," gives you some clues. In it, you try to make some small dunes move.

EXCURSION

Figure 7-12



CONCLUSION

In this chapter you have been primarily concerned with the process of erosion as it affects the midlands. Figure 7-12 is the same diagram you saw on the first page of Part III. If you've done your work well, you should now be able to describe and interpret the features shown. You should also be able to make predictions about the area and what it might look like in the future.

Before going on, do Self-Evaluation 7 in your Record Book.

Excursion 7-1
Gullies and Canyons—A Comparison

PURPOSE

To compare the characteristics of gullies and canyons.

EQUIPMENT

None

MAJOR POINTS

1. The formations of gullies and canyons differ in type of earth material, precipitation pattern of the area, source of the water, rate of water flow, and particle size carried by the stream.
2. Generally, canyons have steep walls, while gullies have gentle slopes.

Look at Figures 1 and 2. The small gully in Figure 2 certainly doesn't look much like the Grand Canyon, shown in Figure 1! However, there is a lot of similarity in the way they were formed.

☐ **1.** What similarities do you see between the two figures?

Figure 1

Figure 2

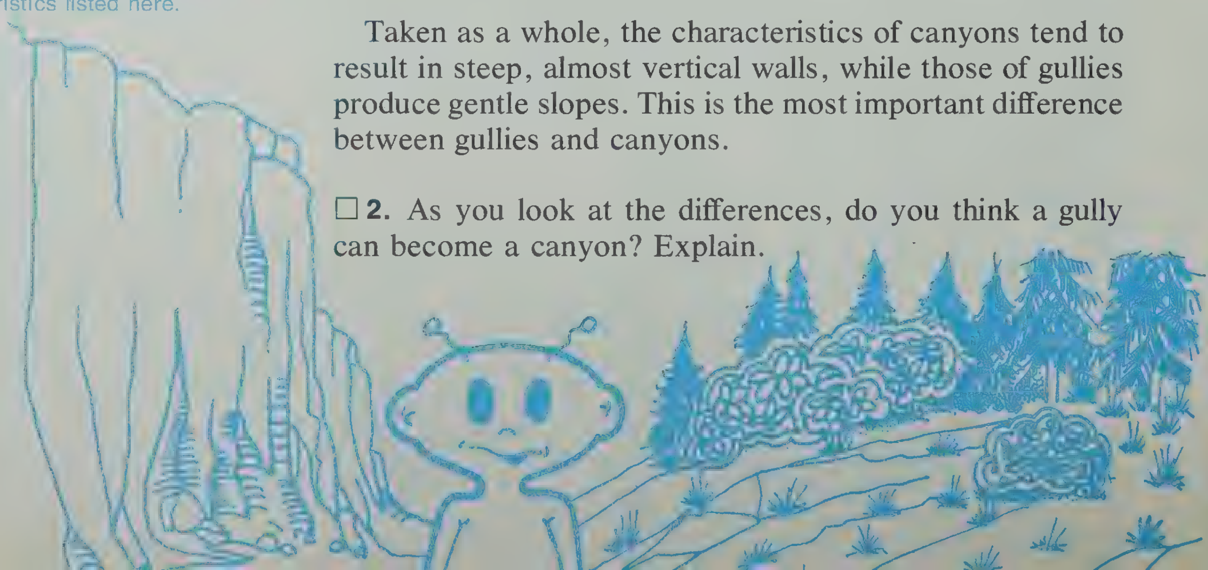
The following list will help you understand the differences between gullies and canyons.

Characteristics of Canyons	*Characteristics of Gullies*
1. The land being carved is usually hard rock, which is quite resistant and breaks up into loose material very slowly.	1. Loose materials from the sides of gullies wash easily into the stream at the base of a gully.
2. Canyons usually form in a relatively dry climate. This means that very little water runs into the canyon from the sides.	2. Rainfall is common where gullies form.
3. The stream doing the carving of canyons usually originates in a much higher area.	3. Runoff water from the surrounding land tumbles over the sides of the main gully and forms many branches.
4. Because the stream comes from a higher source, it moves through a canyon very rapidly.	4. Water flows through a gully at varying rates. The gully deepens most rapidly where the slope is steepest.
5. The fast-moving stream in a canyon carries a large load of rocks. These rocks help cause further erosion.	5. The particles carried by streams in gullies are usually rather small.

2. This question might be a good basis for a small-group discussion. Probably, some places that started as gullies, with relatively loose material, were later classified as canyons. But most of the well-known canyons in the United States are found in areas that have the characteristics listed here.

Taken as a whole, the characteristics of canyons tend to result in steep, almost vertical walls, while those of gullies produce gentle slopes. This is the most important difference between gullies and canyons.

☐ **2.** As you look at the differences, do you think a gully can become a canyon? Explain.



Excursion 7-2

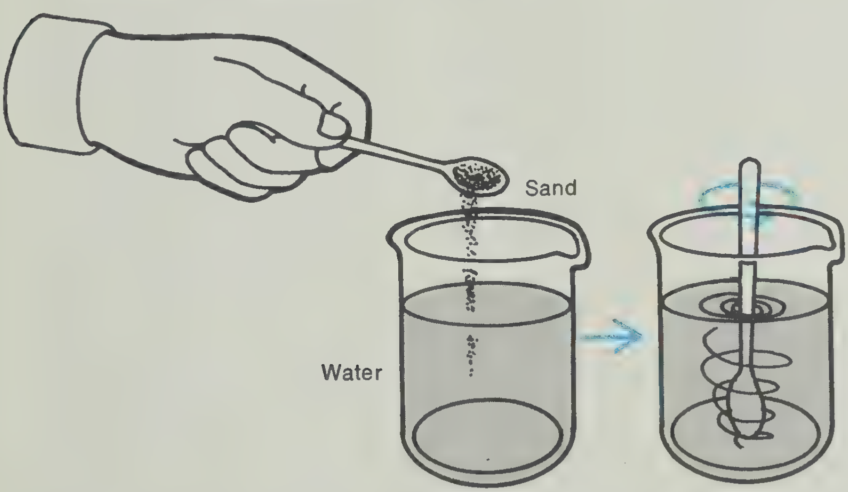
Action of Water Moving in a Curved Path

Most of the stream-table activities deal with water flowing in a straight line. In nature, however, most rivers move through quite a number of curves. Does anything special happen to water that moves in a curved path? If so, does this produce any important effects at places where a river bends? These are questions you will tackle here. To answer them, you and a partner need these materials:

1 complete stream table
1 paper disk, 6 cm in diameter
1 teaspoon white sand
1 beaker

First, you will watch some water moving in a curved path.

ACTIVITY 1. Place 1 teaspoon sand in a beaker three-fourths full of water. Stir the water until it swirls around in the beaker. Observe what happens to the sand.



☐ **1.** Where in the beaker did the sand pile up? Why did this happen? A simple experiment can help you decide.

ACTIVITY 2. Mark the paper disk as shown. Push a pencil through the center of the disk. Hold the pencil between your palms and spin the disk slowly. Notice which letter moves fastest.

☐ **2.** Which letter moves fastest?

☐ **3.** Is the letter that moves slowest near the center, or near the rim, of the disk?

PURPOSE
To investigate the effect of water traveling in a curved path on the erosion and deposition of material, and to investigate the path of a river as it affects the surrounding area.

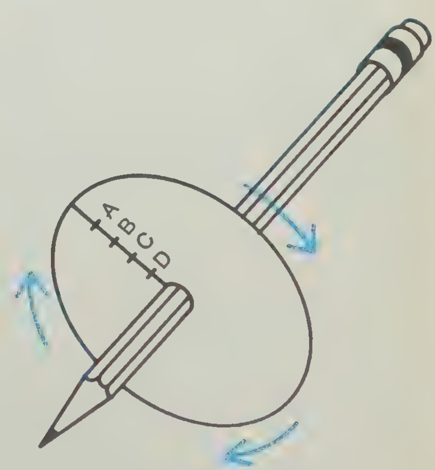
EQUIPMENT

1 complete stream table
1 paper disk, 6 cm in diameter
White sand
1 600-ml beaker
1 teaspoon

A large jar can be used instead of a 600-ml beaker. The jar should be large enough for students to see the deposition of sand in the center. A 1-gallon mayonnaise jar is a suitable size.

MAJOR POINTS

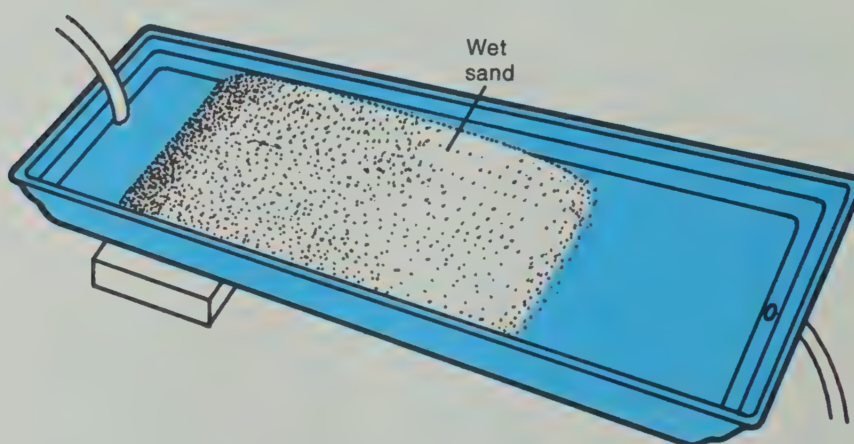
1. Water traveling in a curved path deposits material on the inside of the curve.
2. Water traveling in a curved path erodes material from the outside of the curve.
3. The course of a curving stream changes continually.
4. A river cuts a valley much wider than itself.
5. The winding of a stream (meander) can result in sections being cut off to form oxbow lakes.



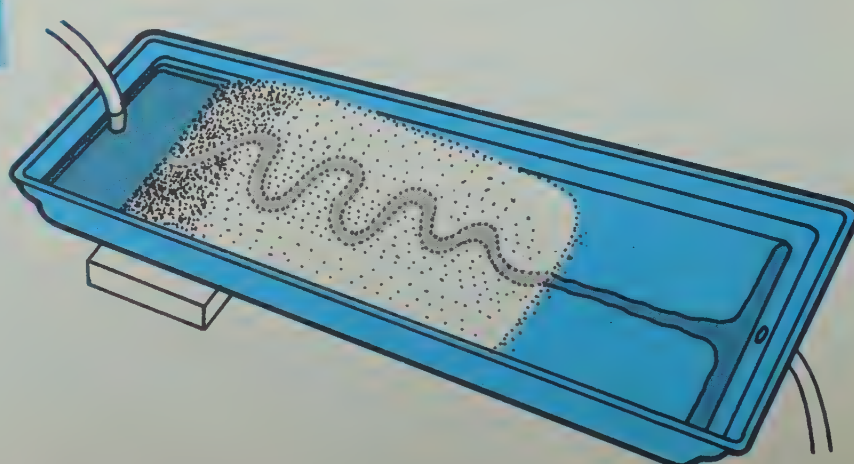
The water moving around near the outside of the beaker clearly traveled a greater distance in the same time than did the water near the center. Described another way, the water near the edge traveled at a greater speed (or velocity) than did the water in the center.

The slower water moves, the more likely it is to drop whatever load it is carrying. This fact is very important as water moves in a curved path. The next activity will allow you to learn still more about this.

ACTIVITY 3. Arrange the sand on the stream table as shown. Be sure that the sand is wet and piled fairly deep. It should be rounded off, as shown.



ACTIVITY 4. Trace a path with your finger as shown. The path should be cut almost to the bottom of the sand (about 2.5 cm deep). Adjust the flow of water into the reservoir to about 5 ml/sec. Allow the water to flow down the path for 20 minutes. Then turn off the water, but leave the sand in place. Don't forget to replace the catch bucket when it gets full.



☐ **4.** In your stream table, on which side of the bend does the water move fastest? How do you know?

Now take a look at Figure 1, which shows the Apalachicola River in Florida, and Figure 2, which shows a small stream in North Dakota. Notice that sand is deposited on the inner parts of each river bend, where the water moves slowest. On the outer part of the curve, the water moves fast enough to keep the sand from falling out. In fact, the water erodes away the outer bank as it rounds the corner.

Interesting, but odd, is the fact that straight rivers tend to stay straight, yet curved rivers tend to curve more.

Figure 1

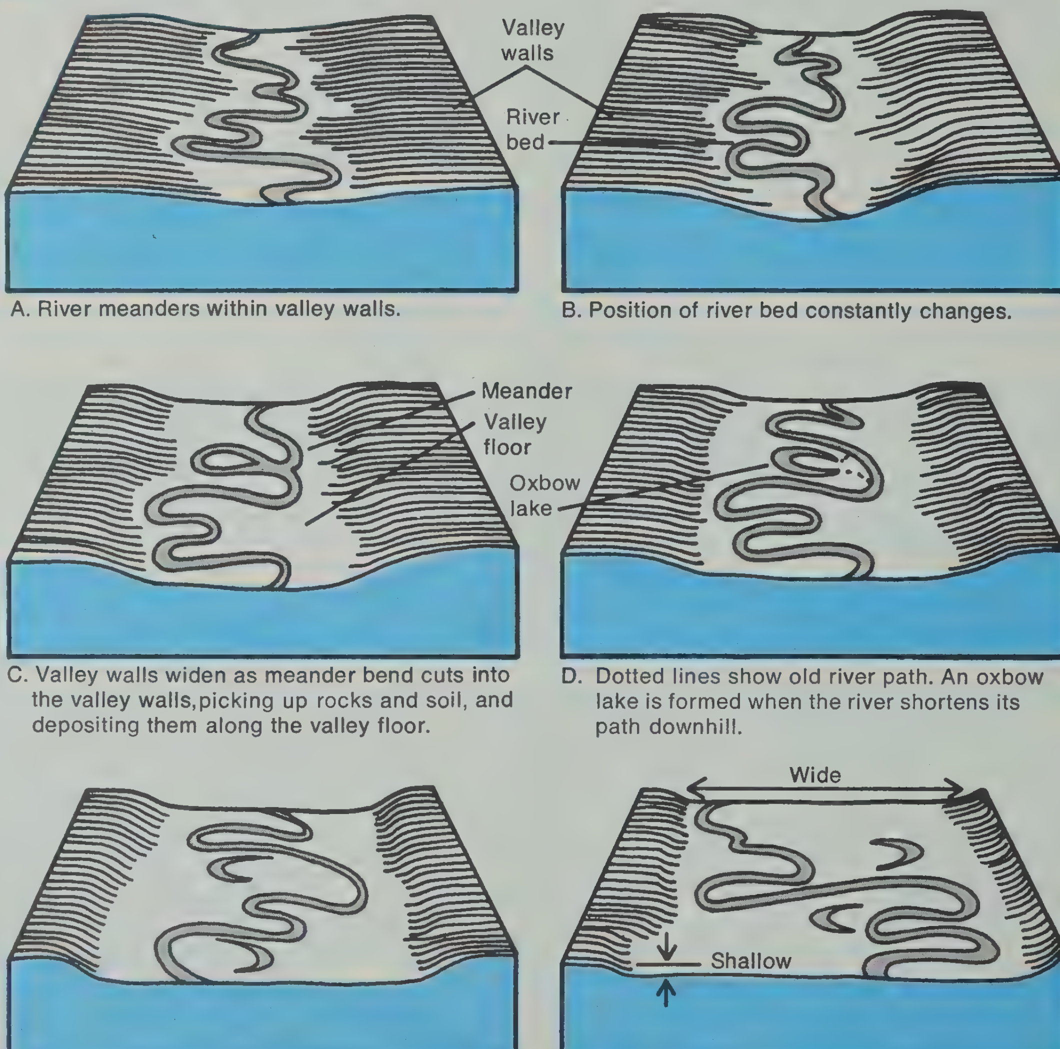
Figure 2

In fairly slow-moving rivers, the bends become more curved as the water erodes one side and deposits sand on the other. Rivers that do this are said to *meander*. But sometimes, during periods of heavy rain, these rivers become flooded, and their rate of flow increases. You can

duplicate this effect by increasing the rate of flow of water into the stream-table reservoir to 15 ml/sec. Notice what effect this has upon the *meanders* in the stream bed.

It is possible, with sufficient time and water flow, to model the formation of an oxbow lake, where the river cuts off one of its deep bends. Of course, water will not remain in the sand lake as it will in nature.

Figure 3



A. River meanders within valley walls.

B. Position of river bed constantly changes.

C. Valley walls widen as meander bend cuts into the valley walls, picking up rocks and soil, and depositing them along the valley floor.

D. Dotted lines show old river path. An oxbow lake is formed when the river shortens its path downhill.

E. The valley continues to widen as the meander moves to the opposite side of the valley.

F. Notice how much wider and shallower the valley has become because of the river carving away the valley walls.

The fact of the river valley being much wider than the river itself is an important one. In almost every section of the country, students should be able to see examples of this in nature.

Excursion 7-3
Delta Formation and Changes in Sea Level

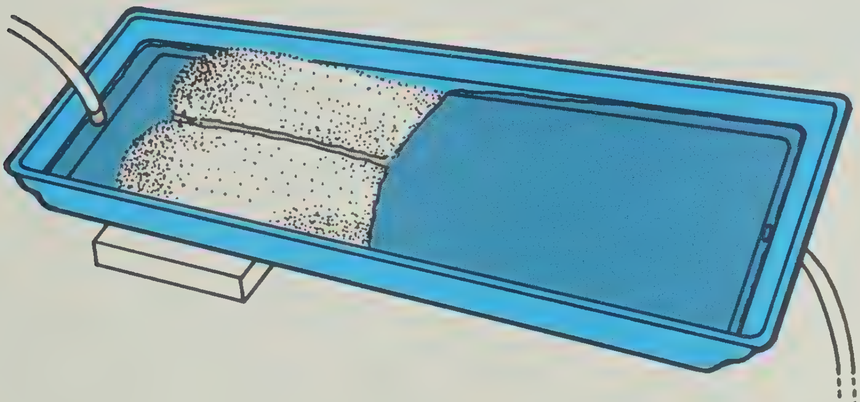
EQUIPMENT

1 complete stream table
Knife
1 baby-food jar

Soil, sand, and gravel dropped at the mouths of rivers build up into fan-shaped deposits called *deltas*. The one at the mouth of the Nile grew slowly over thousands of years, but you can make a model of a delta in a few minutes. (Keep in mind that the stream table cannot duplicate all the conditions of a natural stream.)

Get the complete stream-table setup, a baby-food jar, and a knife for shaping the sand. Then do the following activity.

ACTIVITY 1. Set up your stream table as shown. Adjust the rate of flow into the reservoir to 5 ml/sec. Allow the water to flow for about 10 minutes.



Carefully watch the buildup of the delta. Note what happens to particles of different sizes. Leave the delta in place for Activity 2.

☐ **1.** What size particles travel farthest into the reservoir? Which travel the shortest distance?

What you have just seen in the stream table is very similar to what happens at the mouth of a large river. As the river flows into a sea or lake, it slows down, and its ability to carry sediments (particles) is reduced. As a result, the particles drop to the bottom. A delta is gradually built up from the deposited sediments. Larger particles drop first; fine particles are deposited in deeper, stiller water.

There is much evidence that the level of the seas has changed many times in the past. If the land were to sink a little or the sea level were to rise, the position of the

MAJOR POINTS

1. A delta is the fan-shaped deposit of sediments dropped at the mouth of a river.
2. As a river flows into a sea or lake, it slows down, and its ability to carry sediments is reduced.
3. The larger particles are deposited first, and the finer particles settle in deeper, stiller water.
4. Multiple deltas result when the sea or lake level changes.
5. Rate of stream flow has an effect on the speed and size of delta formation.

shoreline could move. Figure 1 is an aerial photograph that shows how the shoreline has moved on Florida's Gulf Coast. The diagram in Figure 2 will help you understand the photograph.

Figure 1

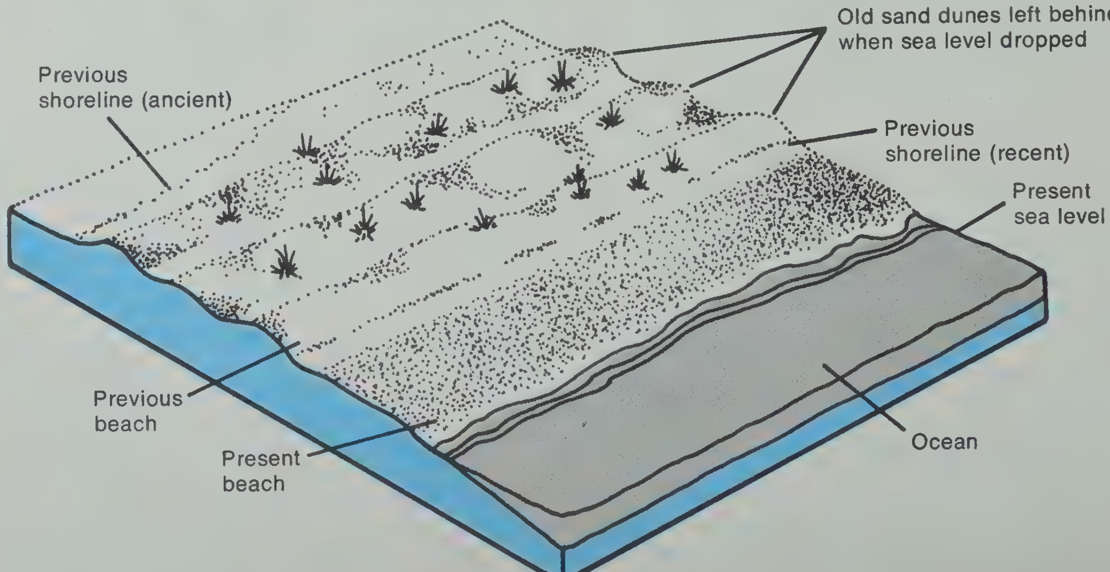
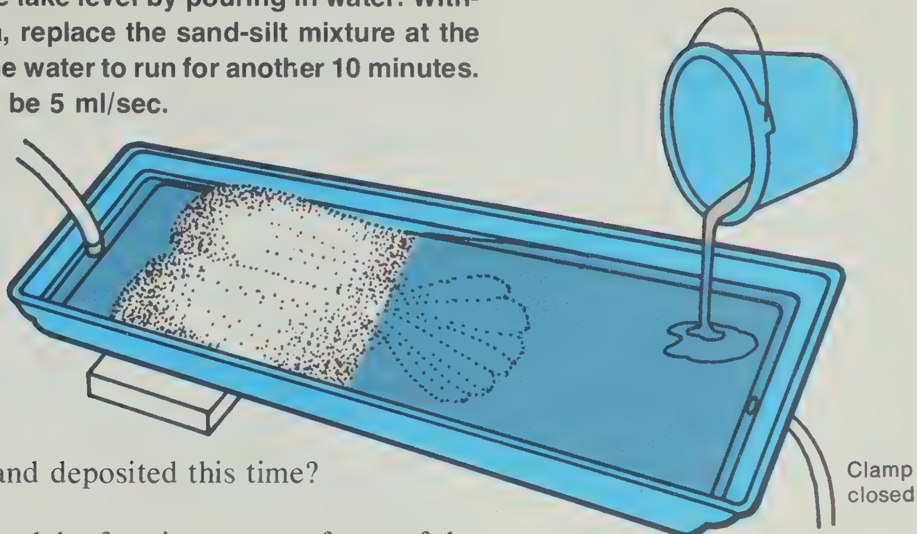


Figure 2

You can use the stream table to show how the changing sea level affects the deposition of materials.

ACTIVITY 2. With the delta from the previous experiment still in place, gently raise the lake level by pouring in water. Without disturbing the delta, replace the sand-silt mixture at the top of the table. Allow the water to run for another 10 minutes. The rate of flow should be 5 ml/sec.



☐ **2.** Where was the sand deposited this time?

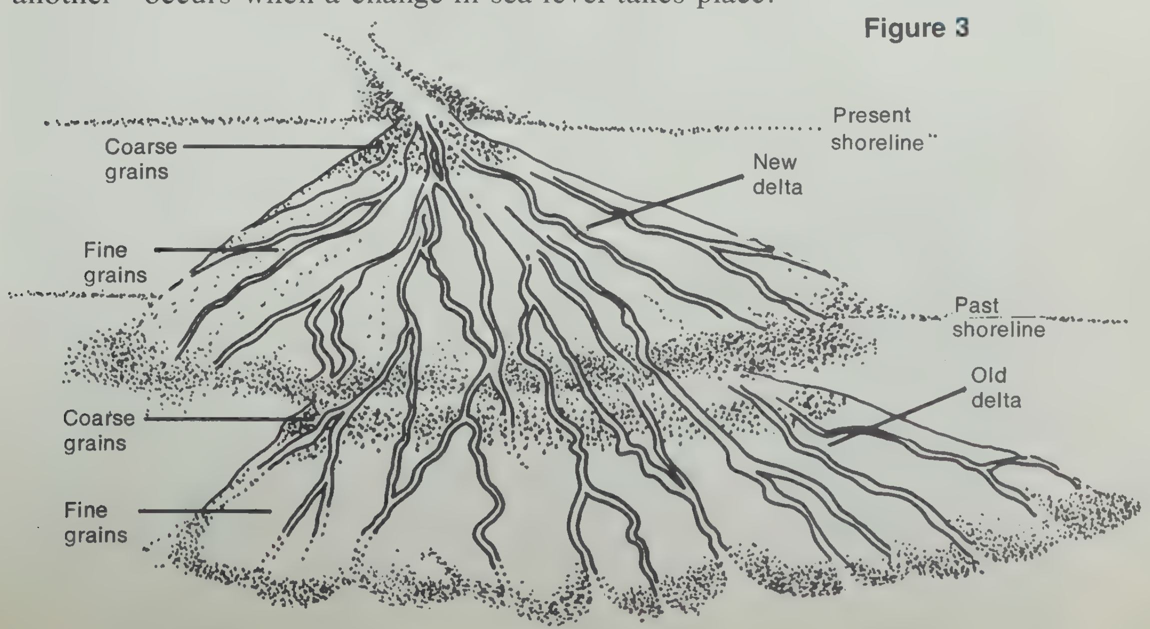
You should see a new delta forming on top of part of the original one. When you see the second delta forming, try creating a "flood" by pouring a baby-food jar of water quickly into the reservoir every half minute. Move the jar as your pour. This will stir up the silt. After 10 minutes, stop the water flow and completely drain the stream table.

You should now have two deltas, one overlapping the other. This situation is illustrated in Figure 3.

You have observed that the particles are sorted out according to size. Where they are deposited depends on a combination of the rate of flow of the stream and the depth of the water. This double delta effect—one delta on top of another—occurs when a change in sea level takes place.

Various factors can cause a change in sea level: the melting of a continental glacier is one of them.

Figure 3



Excursion 7-4
Alluvial Fan Formation

PURPOSE

To investigate how and why alluvial fans form.

EQUIPMENT

1 complete stream table

MAJOR POINTS

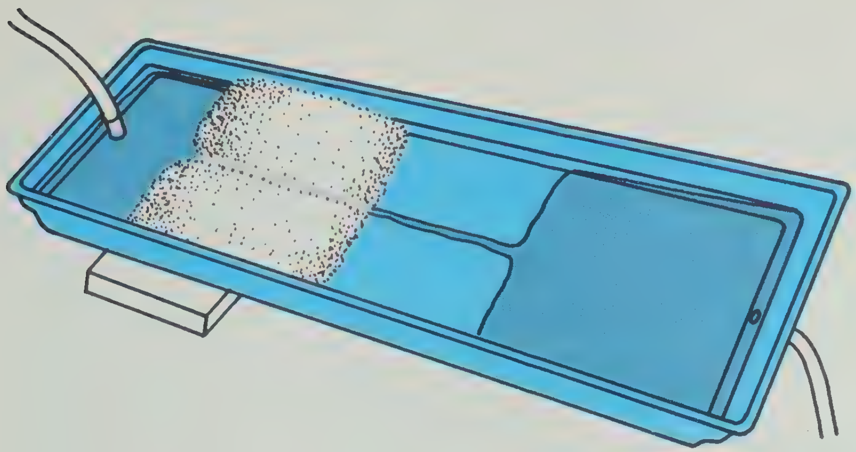
1. A fan-shaped deposit at the bottom of a steep slope is called an alluvial fan.
2. Factors such as amount of water flow, looseness of material, steepness of slope, and variation in water flow may affect the formation of alluvial fans.

When stone, gravel, and silt wash down a steep slope, they may form a fan-shaped deposit at the base of the hill. Such deposits are called *alluvial fans*. Figure 1 shows several alluvial fans in Death Valley.

In this excursion, you will have a chance to investigate how and why alluvial fans form. To do this, you will need a partner and a complete stream-table setup.

Figure 1

ACTIVITY 1. Set up the stream table as shown. Adjust the rate of flow into the reservoir to 5 ml/sec. Allow the water to flow for several minutes. Observe what happens.



Did you get an alluvial fan to form? Once you have suceeded in getting an alluvial fan to form, you are on your own. Vary the procedure outlined in Activity 1 in any way you like. Keep in mind that you are trying to learn what conditions cause alluvial fans to form. Here are some variables you may want to experiment with.

1. Amount of water flowing down the hill
2. Looseness of the materials over which the water flows
3. Steepness of the slope over which the water flows
4. Change in speed of the flowing water

☐ **1.** Describe the best conditions you found for forming an alluvial fan.

Figure 1 shows some white areas in addition to the alluvial fans. The water that brought down the material that formed the fan carried dissolved materials with it as well. In a dry area like Death Valley, water evaporates very quickly, leaving the dissolved material behind. The white material in Figure 1 is mostly salt.

Students should be able to discern, from the activity and from the illustrations, that an abrupt leveling of a stream channel makes it impossible for the stream to carry its entire load. As the load is dropped, a fan is formed. This is a little difficult to simulate with the stream table, because an abrupt change in slope is hard to get.

Note that the technique for simulating alluvial-fan formation is the same as that for simulating delta-formation (Excursion 7-3). In actual situations, the two processes are similar but not identical.

PURPOSE

To develop a model for sand dune formation and movement

EQUIPMENT

1 cardboard box
Fine, white sand

Excursion 7-5
Dunes on the Move

Behind many beaches and on many island desert plains, there are great piles of sand called *dunes*. St. George's Island, in the Gulf of Mexico, has many sand dunes. One of these dunes is shown in Figure 1. You can see the Gulf in the distance, beyond the dune.

Figure 1

MAJOR POINTS

1. A sand dune forms when a wind blows the sand up a gentle slope and drops it in a steep slope on the farther side.
2. Sand dunes move in the direction that the prevailing wind blows.
3. Vegetation or other obstacles can keep dunes from moving.
4. When sand is deposited in layers by wind, the resulting formation is called dune-bedding.
5. The layering of sand in dune-bedding gives evidence as to whether a sedimentary rock is wind-deposited or water-deposited, and can also indicate the direction of the prevailing wind that formed the dune.

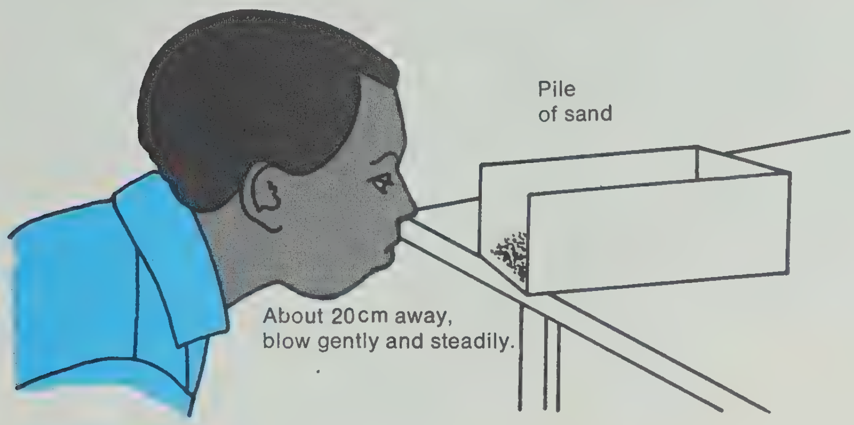
☐ **1.** Predict how the pattern of markings was produced on the face of the dune.

You can check your prediction by finding a partner to help you with this activity. You will need:

Cardboard box (size of shoe box), with one end removed
Handful of clean, dry sand

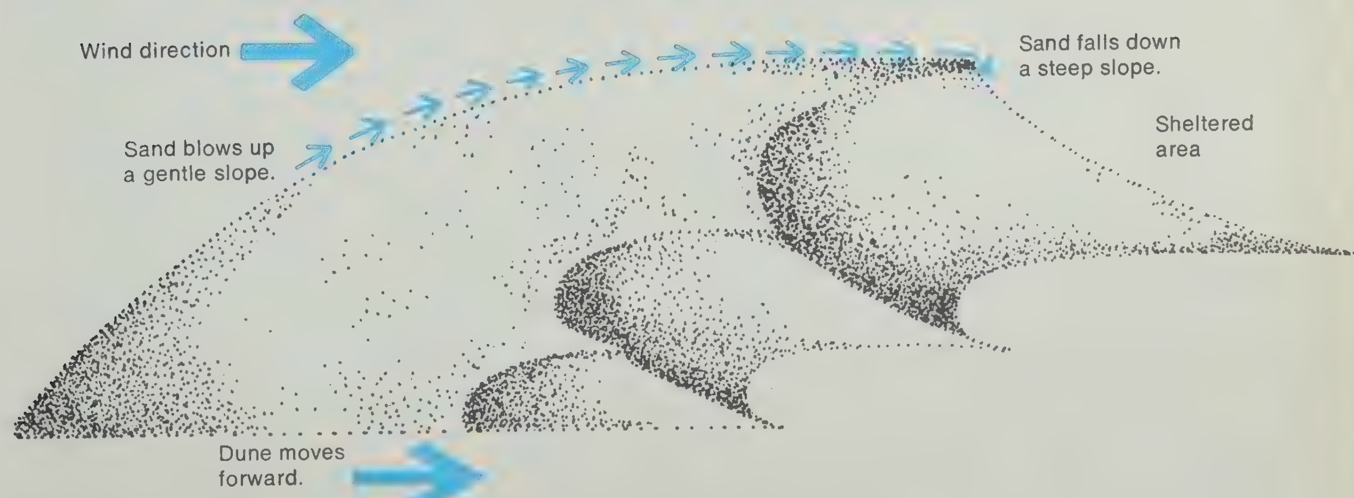
ACTIVITY 1. Build a small sand dune near the open end of your box. Put your mouth level with the bottom of the box, and blow gently but steadily. Move your head from side to side to distribute the wind evenly across the pile of sand.

Take turns with your partner until the sand pile moves about 10 cm.



☐ **2.** What happens to the sand on the side of the pile facing you? What happens on the other side?

Figure 2



You have just simulated the action of the wind on beach or desert sand. In both places, the wind builds up piles of sand called dunes. This process is shown in Figure 2. Dunes

Students can simulate obstacles by pushing projecting small objects (pencils, rocks) into the dune.

can be moved considerable distances each year unless some obstacle slows or stops their progress, as in Figure 3.

Figure 3

☐ **3.** What agent is preventing the movement of the sand dune in Figure 3?

In the experiment you just carried out, you observed the sand grains rolling down the far side of the dune. Imagine a period of weather with little wind, followed by a period with strong wind, followed by another calm period, etc. Then look carefully at Figure 4, which shows a close-up of a dune.

☐ **4.** Describe the layers in the sand dune. (Are the layers parallel, or do they lie at angles to each other?)

An arrangement of this kind is called *cross-bedding*. It is one way of recognizing wind-deposited sedimentary rock.

Figure 4

5. Water-deposited sand generally forms in horizontal layers and is not cross-bedded

☐ **5.** How is the layering in Figure 4 different from the structure of a sand deposit formed in water? (You may want to look back at the water-formed layers in Figure 3-5.)

Figure 5

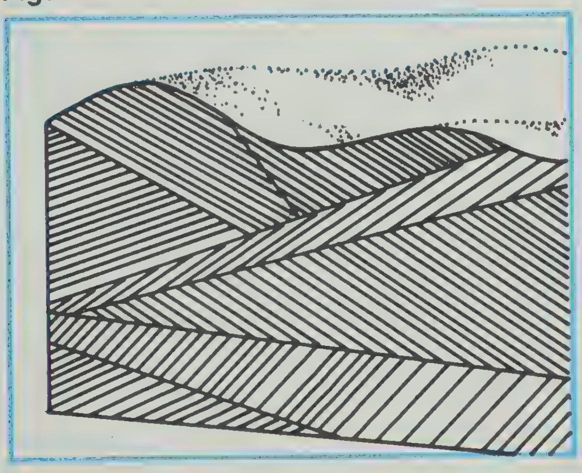
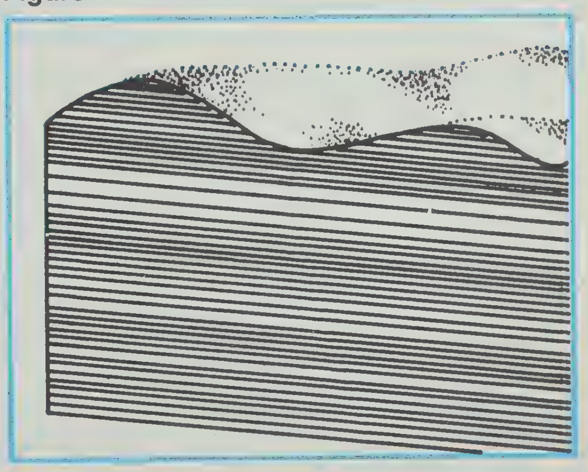


Figure 6



WIND DIRECTION

- Northeast (NE)
- Northwest (NW)
- West Northwest (WNW)
- East Northeast (ENE)

☐ **6.** Which figure (5 or 6) represents dune-bedding? What evidence is there about changes in wind direction?

In this excursion, you have looked at wind transport of sand. Sand grains are blown along near the ground and, in the process, become angular and sharp. They move up the face of dunes and fall down the other side. In this way, a dune may move long distances over a period of years. A new dune starts behind it, and soon a parallel set of dunes is marching across a landscape. Dunes bury objects in their path and may kill vegetation. If the vegetation can grow thick and tall enough not to be buried, it may eventually hold the sand and stop it from moving.

Some vegetation, such as sea oats on the Florida coast, are protected by law because the plants have the ability to grow in beach sand and keep it from moving, thus maintaining the dunes along the beach.

PART IV
The Shorelands

Excursion 8-1 is keyed to this chapter.

Waves and Beaches

8

CHAPTER EMPHASIS

The interaction of ocean waves and the continental margins produces features that are classified as shorelands. Variables such as the energy of waves, direction of wave movement, type of coastline, and tidal changes have an influence on the appearance of the shorelands.

EQUIPMENT

1 complete stream table
1 wooden block
1 notched sand-and-plaster block
Handful of gravel
Sand-silt mixture

Construction of the block out of sand and plaster is described in the front section of this Teacher's Edition, in the section entitled "Preparation of Equipment."

MAJOR POINTS

1. The kinetic energy of waves does work on the coastline and shapes the character of the shore.
   a. Whether a coastline is sandy or rocky is a function of the energy of waves and the type of rock.
   b. Waves eroding a rocky coastline carve out features such as stacks, headlands, and sea caves.
2. The erosive effects of waves on a cliff occur in a narrow band just above sea level.
3. When a crack develops in a cliff, air in the crack is compressed by the waves. The re-

If you've never tasted a peach, you can hardly imagine its flavor. Fortunately, the same problem doesn't exist with land features. The student who lives in an interior state like Iowa may still have a good idea of what the shorelands are like even though he or she has never visited them. In fact, that student may have an even better general idea than a resident of a coastal region. The latter may sometimes think all coastlines are like the one near home. He or she may forget how varied are the lands that border our major lakes, the Gulf of Mexico, and the Pacific and Atlantic oceans. The geologic features of the shorelands are different in different regions.

Study Figure 8-1 carefully. You should be able to see many of the features of the shorelands sector that you first

Figure 8-1

sulting force of compression tends to make the crack bigger.
4. Fragments broken from the cliff cause further erosion when driven by waves.
5. Undercutting of the cliff can cause arches, caves, and pinnacles to form.
6. Material removed from the cliff may form an underwater bench, or a beach.

noted in Figure 2-4. Why is this coastline narrow and rocky in some places and wide and sandy in others? Why are some waves almost straight and others curved, and why do they break where they do? How did the coastline get to be the way it is, and what will it look like in the future?

Those are not easy questions to answer. As you work through Part IV, you should be able to explain how each feature of the shorelands was formed. And you may even predict what might happen in the future.

THE FORCE OF WAVES

Any surfer who has "wiped out" knows about the tremendous force of just a single wave. It is harder to see how this same force changes the land. However, over a period of time even such gradual changes become noticeable.

☐ **8-1.** Which occurred more rapidly, the change from Figure 8-2 to 8-3 or the change from Figure 8-3 to 8-4?

☐ **8-2.** Did the same forces of erosion that brought about the change seen in Figure 8-3 cause the change seen in Figure 8-4? Explain.

8-1. The absence of the cottage in Figure 8-4 is a good indication of a rapid change. A hurricane would be a likely explanation for the change.

8-2. Yes, the sand and the cottage were probably both removed by wave action. The trees appear undamaged, so it likely that wave action rather than wind removed the cottage during the storm.

Figure 8-2

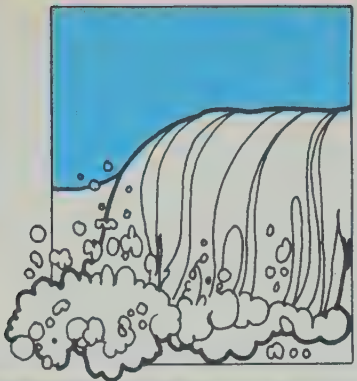
Figure 8-3

Figure 8-4

Some students may feel that the removal of the cottage was due to wind action instead of wave action. This could be the basis of a good group discussion. One of the principal results of the high winds in a hurricane is that extremely high water is driven toward the shore. If this high water occurs simultaneously with an incoming high tide, a rise of 5 m or more in the sea level can occur. This great an increase would have inundated the cottage, undermining the foundation and battering the structure with storm waves of great force. Homes, docks, and other stuctures that can easily withstand the force of the wind alone can be quickly wiped out by the pounding of water. As students work through the next chapter, they will study the effect of a change in sea level on erosion.

Were you able to guess what happened?

The pictures in Figures 8-2, 8-3, and 8-4 were taken over a period of several years. The last picture was taken shortly after a hurricane. (If the owner of the beach cottage had read this chapter before building the cottage, he or she might have chosen a different location! Perhaps you will see why as you continue reading.)



WAVES AGAINST THE BEACH

Most changes along the seashore are not as apparent as those just shown. When you go to the beach, you see the results of many different processes. Look at the two beaches shown in Figures 8-5 and 8-6.

Figure 8-5 shows a beach in Florida along the Gulf of Mexico. Figure 8-6 shows a Maine beach on the Atlantic Coast. Notice some of the big differences in these beaches.

Figure 8-5

Figure 8-6

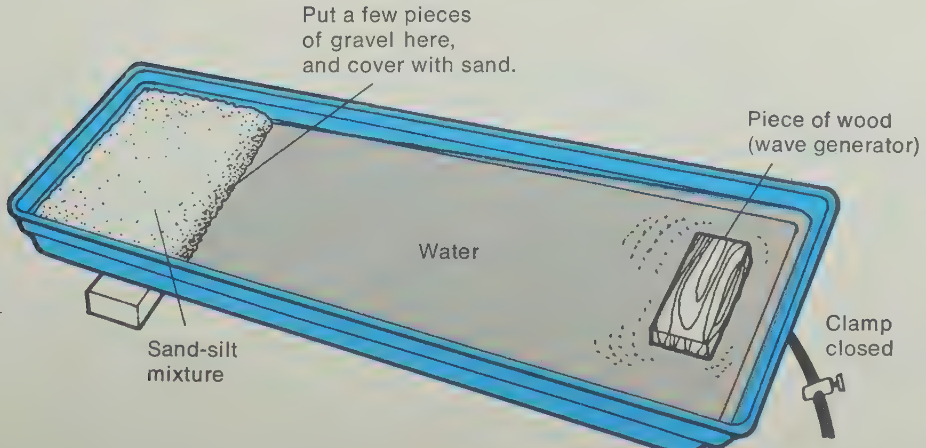
One is sandy with a gradual slope. The other is rocky with a steep drop-off. If you were to dig down through the sand, you would find that the sand layer is very thick. If you tried to dig under the rock beach, you'd probably bend your shovel! During the winter, the rocky beach may be battered by waves 5 metres high. The sandy beach seldom has waves more than 2 metres high.

Waves are produced as a result of energy from winds and storms far out at sea. Waves are carriers of energy. They release energy when they break. This usually occurs near the coast, where the water is shallow.

You can investigate how this energy can affect beaches by using a stream table. Work with at least one partner for the next three activities. You'll need about 30 minutes. You will need a complete stream table, a wooden block, a notched sand-and-plaster block, a handful of gravel, and some sand–silt mixture.

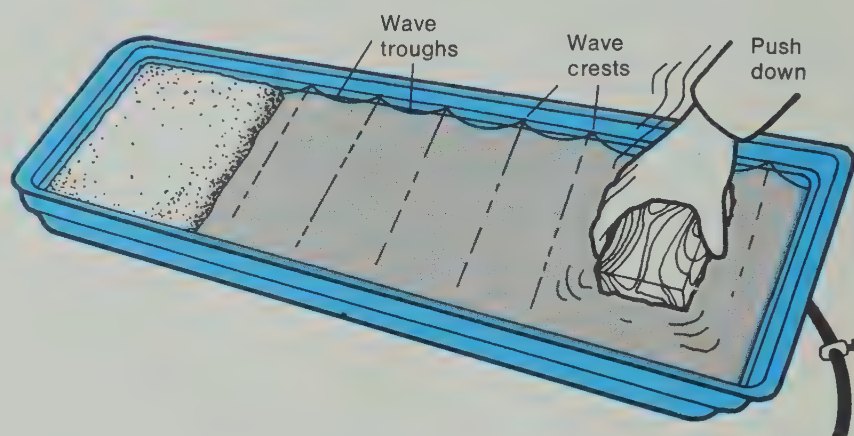
One of the most difficult concepts for students to visualize is change occurring over a long period of time. The rocky beach in Figure 8–6 could become a sandy beach with the passing of sufficient time perhaps thousands of years. The rocks could gradually be ground smaller and smaller, until they become beach sand. Then again, if the waves were strong enough, as in Activity 8-2, the sand that was formed could be carried to deeper water, leaving only the underlying rocks.

ACTIVITY 8-1. Pile the mixture of sand and silt at one end of the stream table to make a sloping surface. Use a block to tilt the table. Then fill with water until the bottom edge of the sand is covered to a depth of about 3 cm. Put a few small pieces of gravel near the water's edge and cover them with sand.



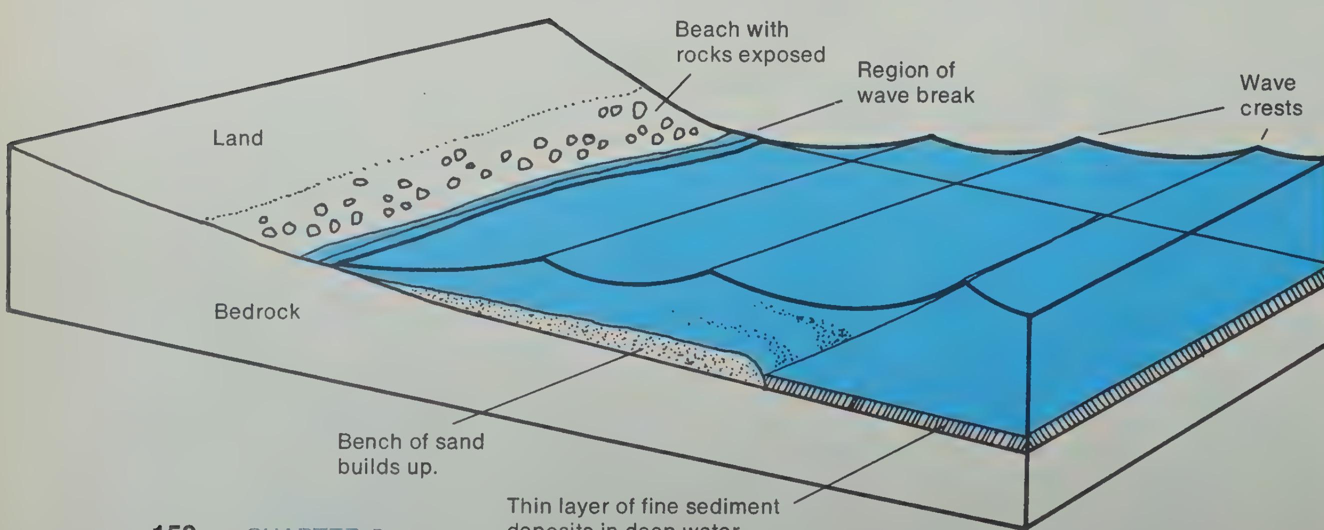
Note the constraint to keep the stream table unaltered in Activity 8-2, in preparation for Activity 8-3. These two activities are sequential and students should be sure to have sufficient time to complete both of them in a single session. In this way, they can best see the two-way transport of the sand—sand moving seaward when there are strong waves and landward when there are gentle waves.

ACTIVITY 8-2. Produce storm waves by pressing down firmly on a piece of wood with the palm of your hand, as shown. Do this once every 3 seconds. Continue for about 5 minutes and carefully observe the sand-silt mixture. Then let the water settle for a few minutes. (Keep the stream table set up and leave the sand exactly as is.)



During storms, high-energy waves reach the shoreline. The action of these waves on the beach is similar to the effect in your stream-table model. The effect should look something like the drawing in Figure 8-7.

Figure 8-7

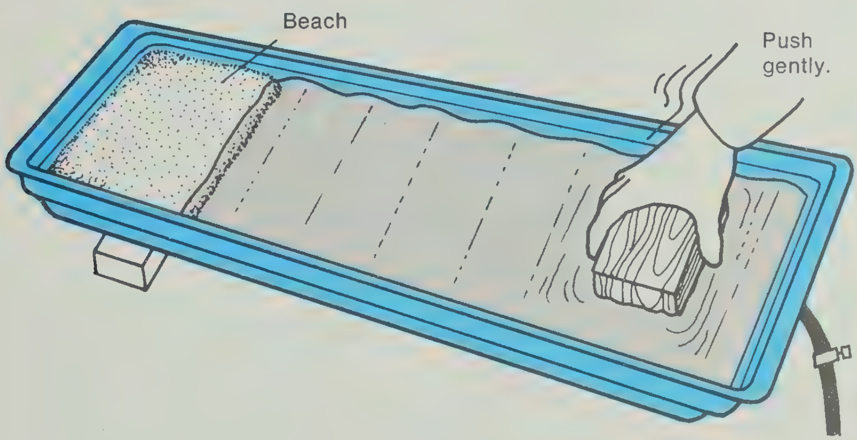


The strong waves attack the beach, shifting the sand out to sea to form a *bench*. Rocks are exposed along the shore. Most of the very fine particles are carried out into deep water, where, in calmer weather, they slowly drop to the bottom.

Some shorelines that are exposed to high-energy waves all the time may not have any sand. Only smooth pebbles are left on such shores.

Note the introduction of the term *bench*. Fundamentally, the difference between a bench and a beach is in their shapes. A bench is a *level*, elevated formation along a shoreline, either above or below the water. A beach is defined as a *sloping* shore of a body of water.

ACTIVITY 8-3. Continue your experiment, using the same stream table that was exposed to high-energy waves. Leave everything as it was. This time, however, push very *gently* so that you produce low-energy, gentle waves. Continue this for at least 5 minutes. Watch what happens when the waves reach shore.



☐ **8-3.** What effect do the low-energy waves have on the beach? How is this different from the high-energy storm waves crashing into the beach?

If there is sufficient time available, encourage students to continue with the *gentle* wave action for a longer period. The beach-building activity can be interesting and instructive.

This time, you should have observed the slow building up of the beach. In fact, if you were patient enough to keep the gentle waves going for a long time, you might have covered up the gravel exposed during the storm. The waves will gradually shift the sand back from the underwater bench onto the beach.

The "Going, Going, Gone" pictures in Figures 8-2, 8-3, and 8-4 show what can happen to a beach when high-energy waves attack it. Storms increase the energy reaching the

shore and cause the erosion of beaches. In good weather, the energy level decreases, and beaches build up again. This cycle of change is always going on, wherever the land meets a large body of water and where the shoreline is suitable for beaches to develop.

EXCURSION

If you are interested in why waves form and break, and where they get the energy to carve a shoreline, do **Excursion 8-1**, "Kinetic Energy and Waves."

WAVES AGAINST A STEEP SHORELINE

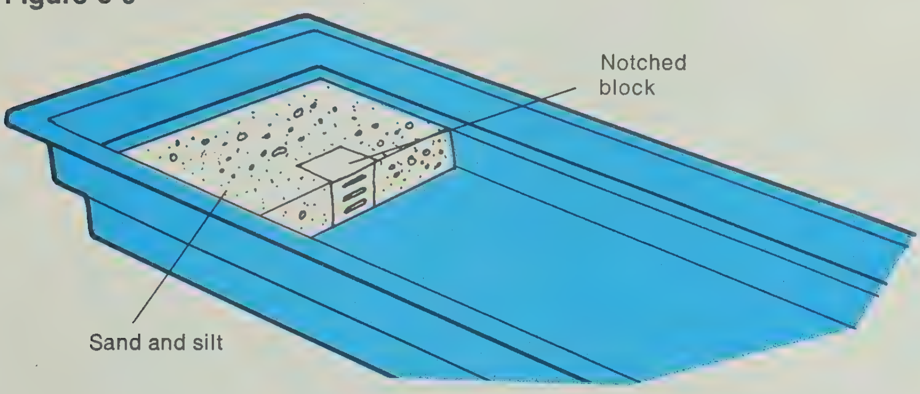
Ocean waves do a great deal of work as they shape and change coastlines and beaches. You have just experimented with the effect of waves on a relatively low-lying shoreline. Figure 8-8 shows waves approaching a rocky coastline with steep cliffs.

Figure 8-8

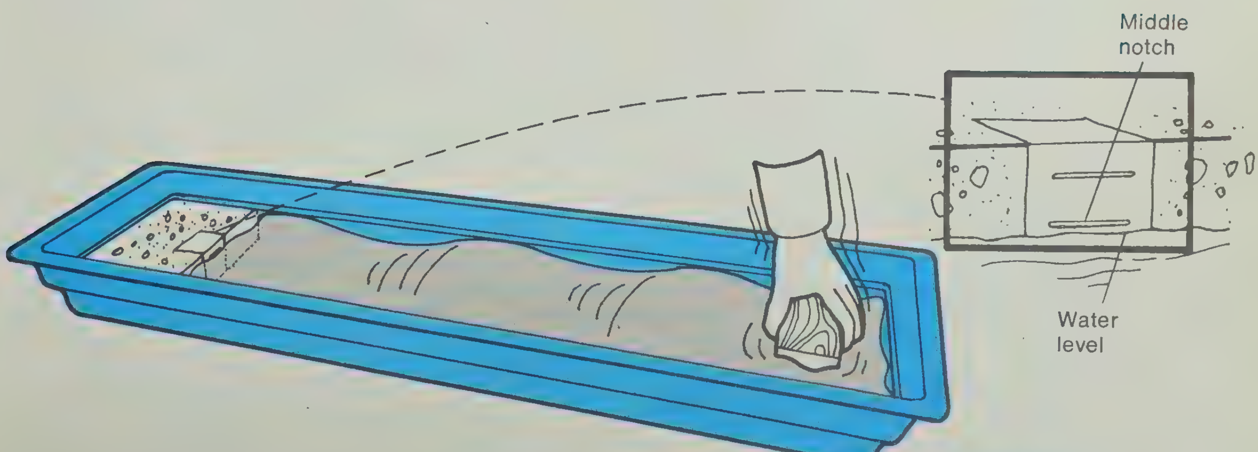
When water crashes into rock, which is stronger—the water or the rock? Obviously, the rock is stronger because it hardly changes, while the water is sent flying in all directions. Yet, over a long period of time, water can destroy huge cliffs of rock.

To simulate this process, get a wooden block, a notched block made of sand and plaster of paris, and some sand-silt mixture. Set up the stream table as shown below. Scatter some gravel on the sand.

Figure 8-9



ACTIVITY 8-4. Fill the stream table with water so that the middle notch in the block is just above the water level. Now generate waves by pushing the wooden block up and down every 5 seconds. The waves should just hit the vertical face of the notched block. Keep the waves going for 5 to 10 minutes, carefully observing the notched block.



☐ **8-4.** Which notch is most affected by the wave action?

From this simulation experiment, you should have seen that the greatest erosion occurs in a narrow band just above sea level. At this level, waves produce an effect such as that shown in Figure 8-10. Softer rocks are more rapidly eroded than harder ones. Cracks allow erosion to proceed faster. This type of erosion in a cliff is called *undercutting*.

Let's examine the effect of cracks at sea level a little further. Figure 8-11 shows a crack at sea level.

Figure 8-10

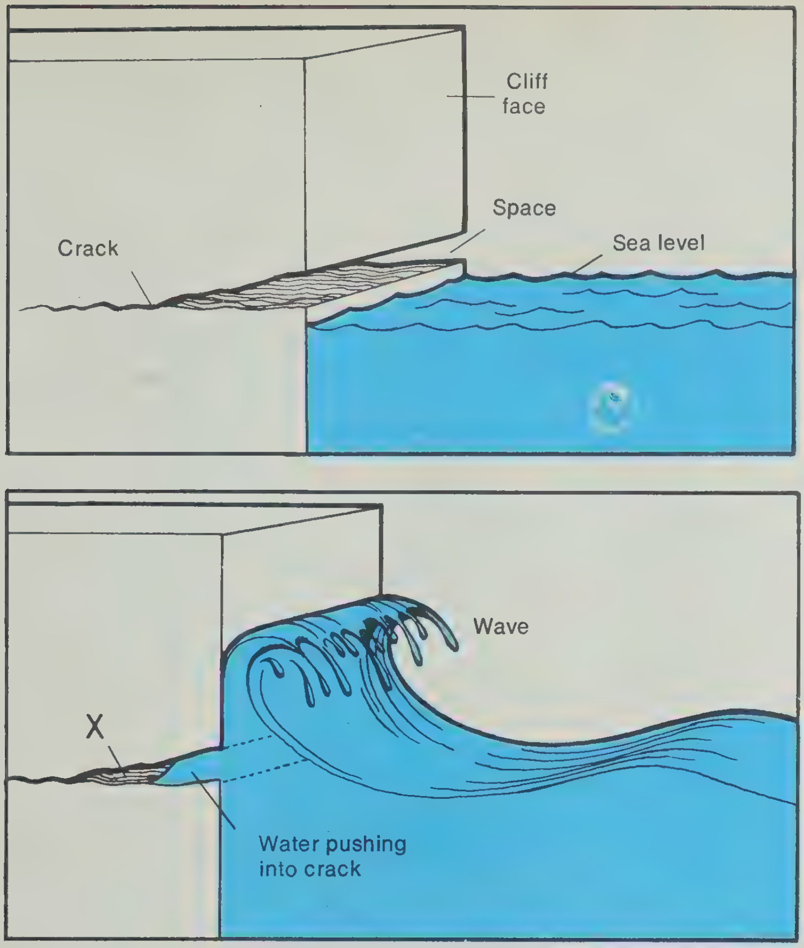


Figure 8-11

☐ **8-5.** What does the space in the crack contain when there is no water washing into it?

☐ **8-6.** What happens at X in Figure 8-11 when a big wave washes into the crack? What effect would this have on the crack?

Imagine this process continuing in the same crack for hundreds of years. Each time water rushes into the crack, the air in the crack is compressed. The force of compression helps make the crack bigger and longer.

In your experiment, you may have seen little broken pieces of plaster tumbling down from the block. These represent pebbles and boulders, which would be broken off a cliff in the real situation. Some of these would be small enough for the waves to pick up and throw against a cliff.

Both the rocky Atlantic coast in Maine and the Pacific coast of Oregon and California show examples of caves, arches, and pinnacles. In some cases the grinding of rocks to sand has formed a beach; in others, the wave action has not had a long enough time to accomplish this, and there is still only a rocky shore.

☐ **8-7.** What effects do waves have on a coastline like the one shown in Figure 8-8?

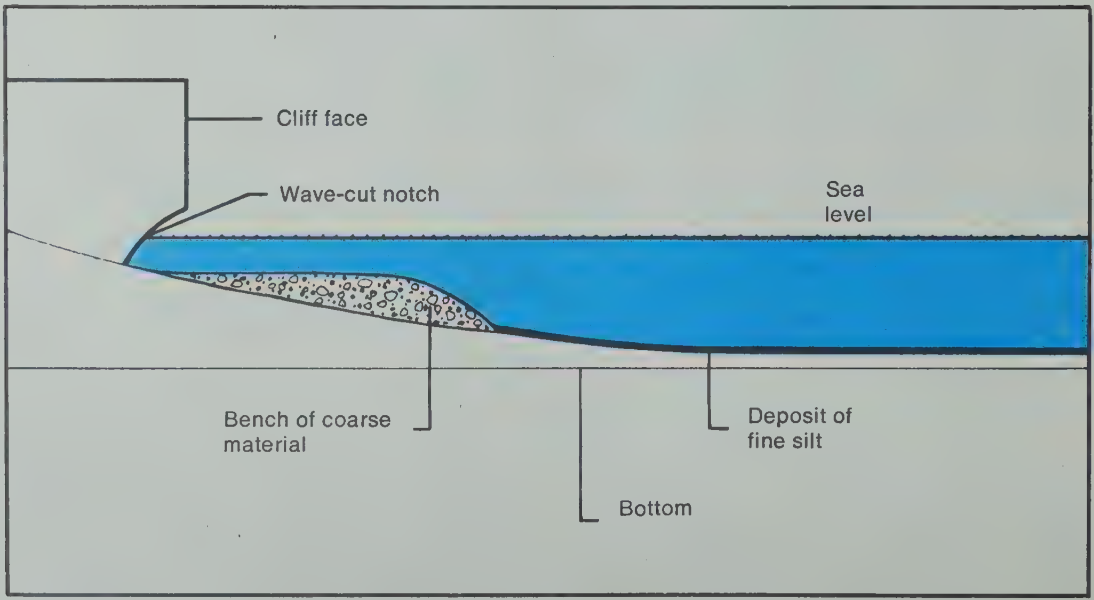
In any coastline region where cliff faces are raised against the sea, the kinetic energy of waves does work. The cliff gets undercut at sea level by the abrasive action of stones and the compression of air in cracks. Arches and caves develop. As these enlarge, they collapse, leaving columns of rock standing by themselves.

The pieces of rock that break off the cliff are ground into sand. Eventually, the sand grains are transported away and deposited elsewhere as offshore benches or as beaches and sandbars.

Now that the water in your stream table has settled down, take another good look at the model you have produced. You should find that the coarser sediment has formed a bench in front of the cliff. The very fine material should be deposited in the deeper, "offshore" water.

☐ **8-8.** How does the arrangement of material in your stream table compare with the diagram in Figure 8-12?

Figure 8-12



Before going on, do Self-Evaluation 8 in your Record Book.

Excursion 8-1

Kinetic Energy and Waves

EQUIPMENT

None

PURPOSE

To study the motion of the water in a wave.

Did you ever notice that a surfer moves toward shore only on a breaking wave? Out beyond the breakers, the surfboard bobs up and down in almost the same spot.

The surfers in Figure 1 have gained kinetic energy as they moved toward the shore. Why doesn't a surfer beyond the breaking wave have the same kinetic energy? What causes the waves to break when they reach shallow water?

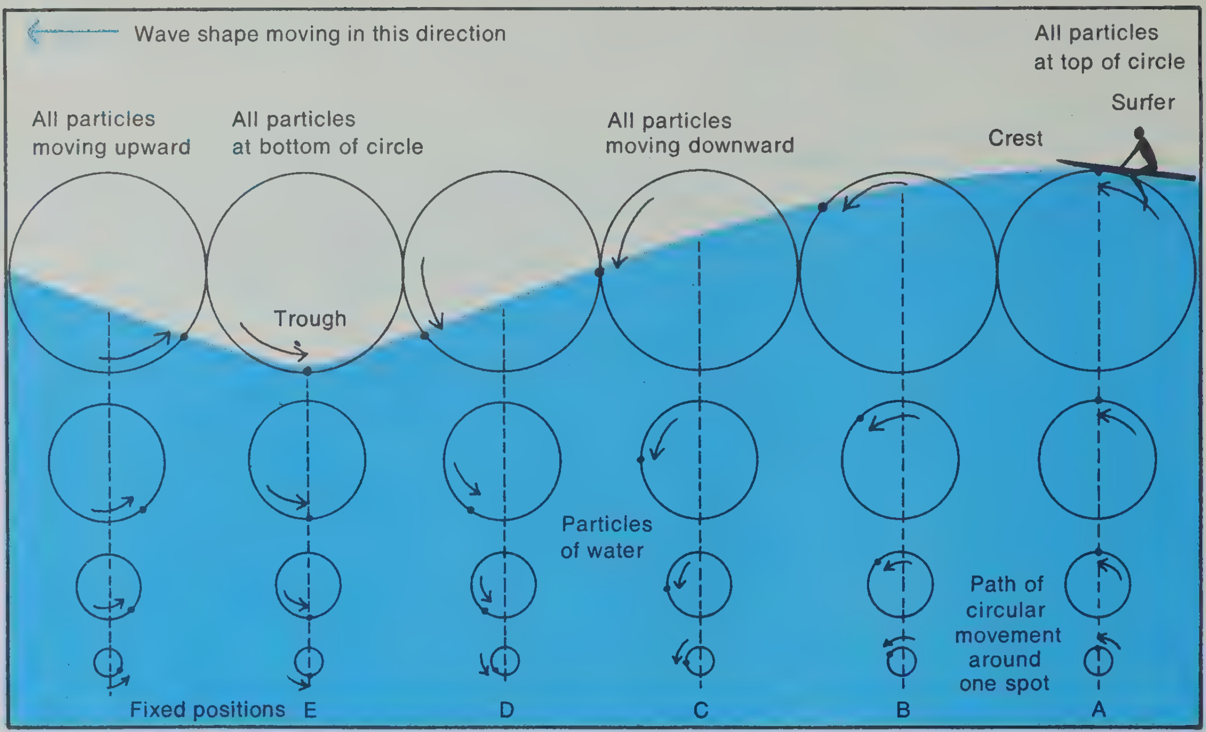
One model of wave action states that water particles in the upper layers are rotating because of wind action. At the high point of the wave (the crest), the particles have rotated up to their highest position. At the lowest point (the trough), the particles have rotated back down to their lowest position. A surfer is lifted and lowered by this rotational motion but is not carried to shore, as shown in Figures 2 and 3. Although the wave's energy (obtained from the wind)

MAJOR POINTS

1. Waves are formed by wind action, far out at sea.
2. The waves travel toward shore, although individual water particles do not.
3. When waves encounter a shallow area, the ocean bottom interferes with the rotational motion of the water particles, causing the wave to break.

is carried forward, the water particles themselves do not move toward shore. They only rotate in a confined area.

Figure 2



In shallow water, as the rotational motion is slowed by the friction against the bottom, the crest of the wave starts to "lean" in the direction of wave motion because of inertia. When the lean gets too great, the break occurs. A surfer starts riding the wave when it starts to lean, and before it actually breaks.

If the water is deep, rotation can occur without interference, and the waves are undisturbed. But imagine what happens when waves get close to shore. What causes waves to break when they reach shallow water?

When the water gets shallow, the particles no longer have room to rotate as before. At this point, the wave breaks. The circular energy of the waves is changed to forward motion of water particles, which rush up the sloping shore. The breaking wave pushes floating objects ahead of it and picks up tons of sand as it rushes toward the beach.

☐ **1.** Where do most waves form? Where does their kinetic energy come from?

☐ **2.** Why do waves break as they near shore?

The size of the waves depends on the strength of the wind. The largest waves occur when a strong wind blows over a large open stretch of water.

☐ **3.** Would you expect waves on the Gulf of Mexico to be generally larger, or smaller, than those on the Atlantic Coast? Explain your answer.

It may be useful to have a map of the United States posted so that students can compare the size and location of the Gulf of Mexico and the Atlantic Ocean.

Figure 3

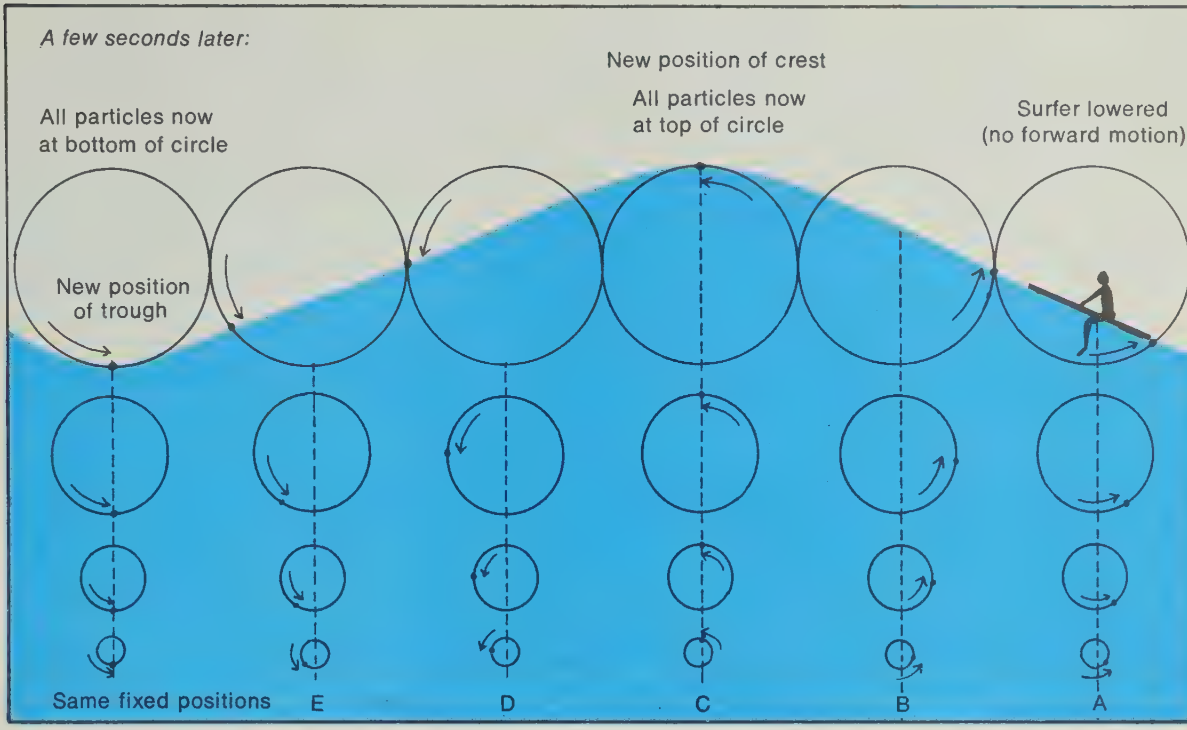
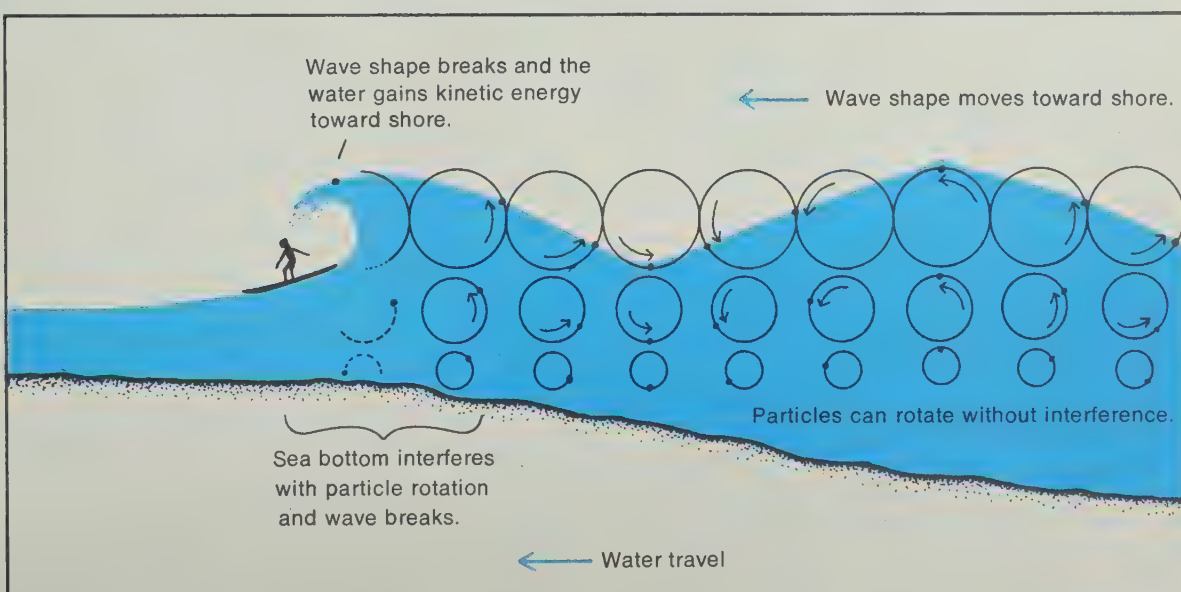


Figure 4



Other Ocean Motions

9

Excursions 9-1 and 9-2 are keyed to this chapter.

FILMSTRIP KEY

Enrichment
Weathering and Soils

CHAPTER EMPHASIS

This chapter continues the study of the effect of waves and tides on the shape of the shorelands.

EQUIPMENT

1 complete stream table
1 wooden block
3 plaster blocks (1 small and 2 large)
Sand–silt mixture

The plaster blocks should have the following dimensions:
Small: 10 cm × 2.5 cm × 2.5 cm
Large: 10 cm × 5 cm × 5 cm

Construction of these blocks is described in the front of this Teacher's Edition, in the section entitled "Advance Preparations" (Part C).

MAJOR POINTS

1. Changing the level of the sea in relation to the land results in wave erosion at different elevations.
2. The nature of the shoreline has an effect on the shape of the incoming waves.
3. Waves approaching shorelands at an angle change direction by the process of refraction.
4. When waves strike an obstacle, their path changes by a process known as diffraction.
5. Longshore drift refers to the process by which sand is shifted along a beach.

In Chapter 8, you saw that ocean waves do a great deal of work in shaping and changing coastlines and beaches. In Chapter 9, you will continue your studies of the effects of waves on the landscape.

The figure on the opposite page shows some features of a typical rocky coast. There is a large rock outcrop with a sea cave and a sea arch. Look carefully near the top of each. Can you see evidence of the high-tide line? (Hint: Look for a change in color.) Also observe the shape of the beach.
The top of the cave is just above high-tide level.

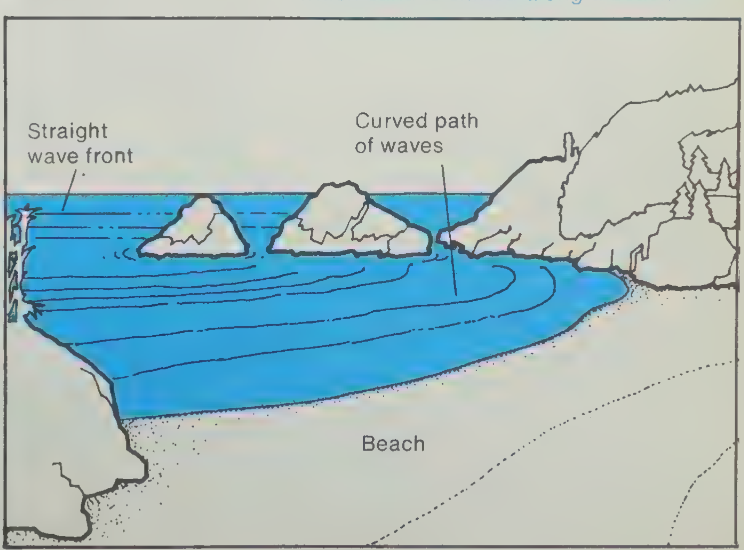
☐ **9-1.** Based on your study of waves and their effects, what evidence is there of wave action on the shoreline?

COVES AND BAYS

If you look at Figure 9-1, you see a series of waves entering a cove. On closer inspection, you see that the waves within the cove take on a curved path. The diagram in Figure 9-2 shows the curved fronts approaching the shore.

Figure 9-1

Figure 9-2

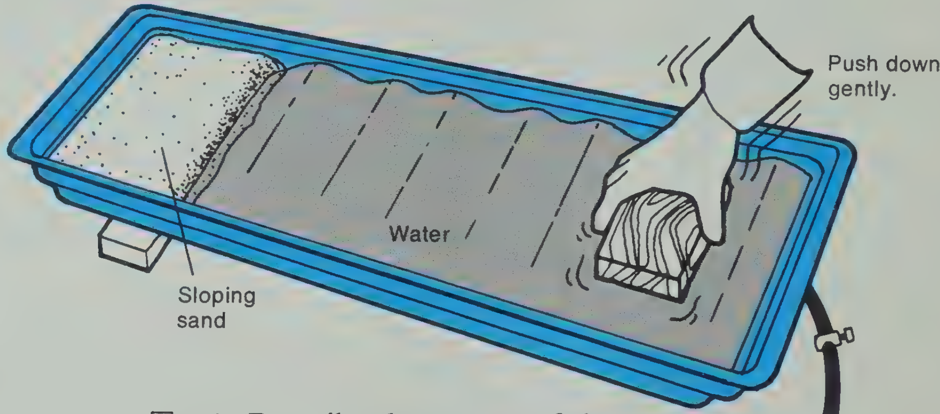


In generating parallel waves, it is important that the wooden block be long enough to come within a few centimetres of the edges of the stream table, and also that the front edge of the block be kept parallel to the beach. The time required to see a noticeable effect will depend on the exact nature of the sand–silt mixture and upon the way the student generates the waves. 3–5 min should be sufficient for this activity.

☐ **9-2.** Suppose you were standing anywhere on the beach shown in Figures 9-1 and 9-2. In what direction would you see the waves coming?

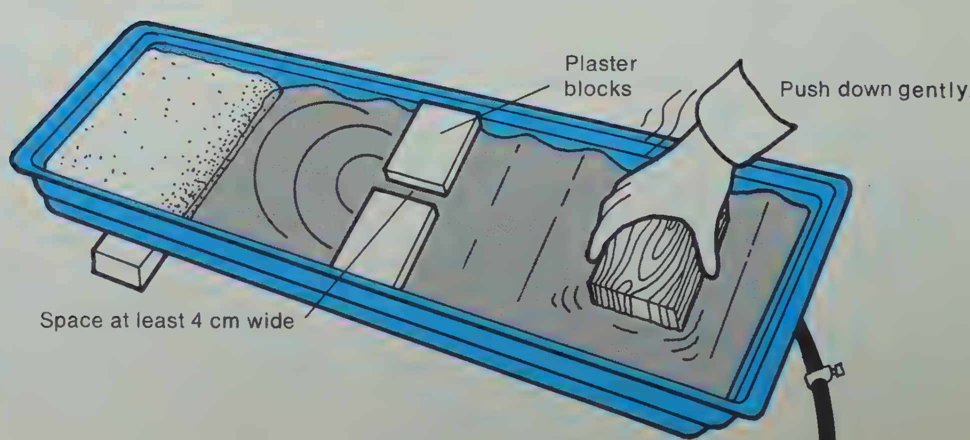
You can understand this pattern and the effect it might have on a shoreline by doing a stream-table activity. You will need a partner, one stream table, two plaster blocks, one wooden block, and some sand–silt mixture.

ACTIVITY 9-1. Set up the stream table with a sloping sand beach at one end. The water should be about 2 cm deep where it meets the beach. Generate waves by gently pushing the wooden block up and down rhythmically every 3 sec. Notice the pattern of the waves.



☐ **9-3.** Describe the pattern of the waves.

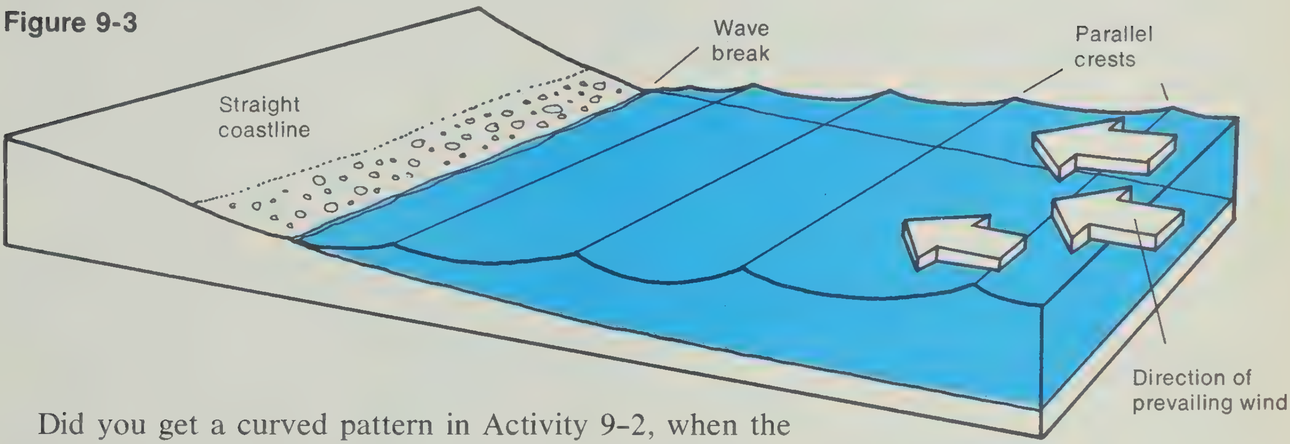
ACTIVITY 9-2. Now put 2 large plaster blocks into the water as shown. The blocks should have a space of at least 4 cm between them and should be above the water level. Generate waves in the same way that you did in Activity 9-1.



☐ **9-4.** How is the wave pattern different from that observed in Activity 9-1? How is the effect on the beach different?

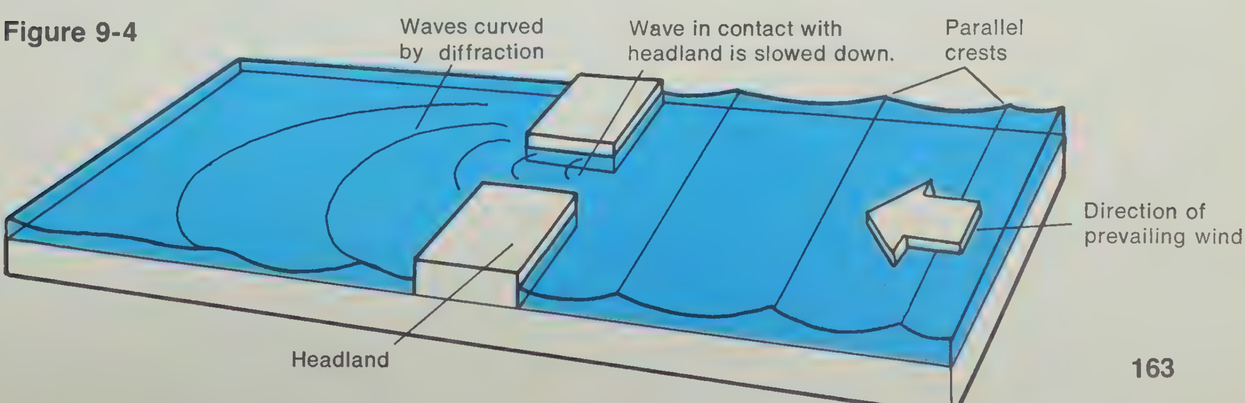
Where a prevailing wind is blowing toward land at right angles to a straight coastline, the wave pattern is like the one you observed in Activity 9-1. The crests approach the coastline parallel to each other and to the coast. This causes uniform erosion all along the coast. Figure 9-3 shows the typical wave pattern for these conditions.

Figure 9-3



Did you get a curved pattern in Activity 9–2, when the waves passed through the gap between the plaster blocks? The plaster blocks represent high points of land that jut out into the sea. These are called *headlands*. The headlands create an obstacle in the water. When parallel waves pass the edge of an obstacle or pass between obstacles, the crests curve. This is called *diffraction*. Your second experiment should have produced a pattern like the one in Figure 9–4. Compare it with the photographs at the beginning of the chapter.

Figure 9-4

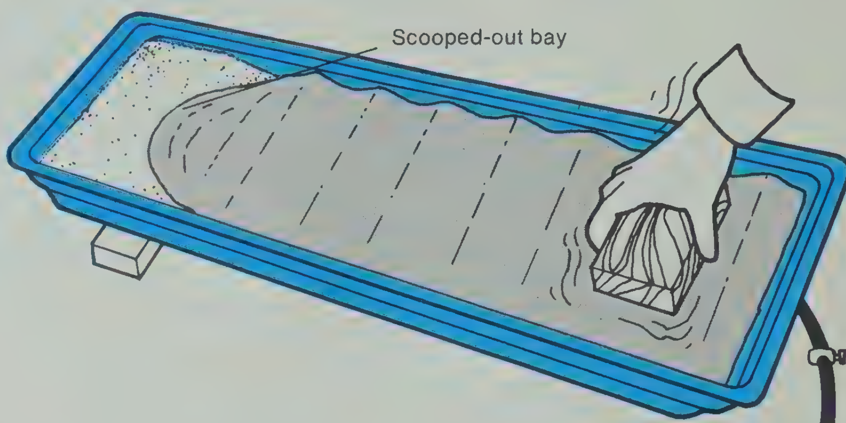


Another thing that changes the shape of a wave is the shape of the coast. Where a coastline is curved rather than straight, some parts of the wave line reach land before others. The parts that reach land first are slowed down, whereas the other parts continue at the same speed. The wave line bends, and this is called *refraction*.

☐ **9-5.** Predict what wave pattern you would get with waves entering a wide, curved bay.

The greatest energy of the waves is concentrated on the heads of the curved bay. Gentle wave action should move sand gradually into the pocket beach. Beautiful bay beaches are formed in this way.

ACTIVITY 9-3. Pile your sand mixture at one end to make a deeply curved, scooped-out bay. Generate waves as you did before.



Did you predict correctly? Where is the greatest beach-forming activity? This activity should help you understand how wave refraction helps form beaches at the heads of curved bays, as well as pocket beaches between headlands.

☐ **9-6.** What type of wave pattern explains the shape of the bays in the photographs at the beginning of the chapter?

LONGSHORE DRIFT

What happens to a coastline when the wave pattern reaches the shore at an angle most of the time? Imagine a wave pattern approaching a beach as shown in the overhead view in Figure 9-5.

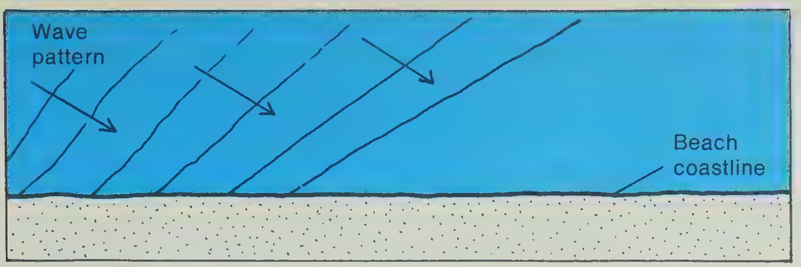


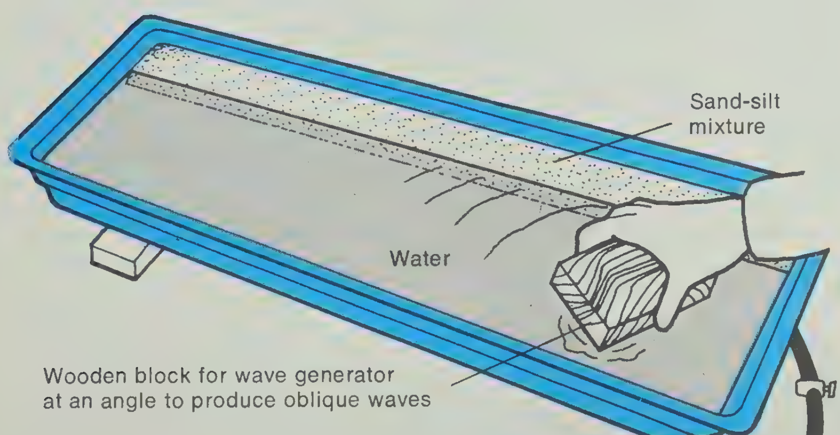
Figure 9-5

☐ **9-7.** Predict what will happen to the shape of the wave pattern when the waves reach the shore. State or sketch your prediction.

Now get a partner, a complete stream table, a piece of wood, and two plaster blocks. You can do a simulation experiment to see the effect of this type of wave action on a beach. This will help you see if your prediction was correct.

ACTIVITY 9-4. Pile the sand-silt mixture along one side of the stream table. Put water into the table to a depth of about 3 cm. The piece of wood you are using as a wave generator should be placed at an angle to the shore. Push down on the wood about every 3 sec. Watch the wave pattern and the erosion effect carefully.

3–5 min should be sufficient to see a noticeable effect.



Did you predict the wave pattern correctly? What happened to the beach?

In your simulation experiment, the wave pattern curves into the beach, and the sand is shifted steadily along the shore. This process is called *longshore drift*.

EXCURSION

When people use beaches for recreation and homes, they often build structures to reduce beach erosion. If you would like to see what these structures do, try **Excursion 9-1**, "Building Seashores."

ANOTHER OCEAN MOTION—TIDES

Figure 9-6 shows two photographs of the same ship, docked at the same pier, on the same day. One picture was taken several hours after the other. As you can see, the level of the water has changed drastically.

Figure 9-6

One of the most noticeable events that affects the shoreline is the daily rise and fall of the tides. The difference between high tide and low tide in the United States can be as much as 3 metres. In some parts of the world it can be more than 9 or 10 metres. Aside from the sea, only the large lakes have measurable tides. Lake Erie has a tidal range of only 8 cm. If you are interested in how tides are measured, try **Excursion 9-2,** "Measuring Sea Level."

EXCURSION

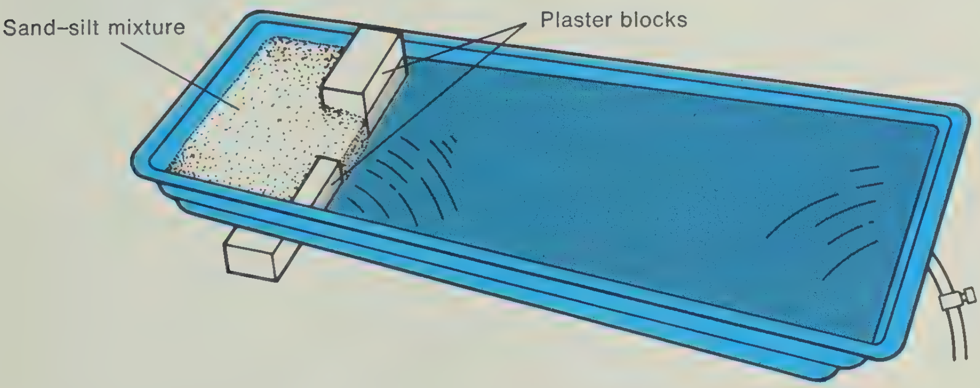
Long ago, people noticed that tides follow daily cycles. They also noticed that the tides changed with the seasons. Today we explain tides in terms of the gravitational attractions of the moon and the sun, which cause the water on the

earth's surface to bulge out. The moon, though smaller than the sun, has a greater effect because it is so much closer to the earth.

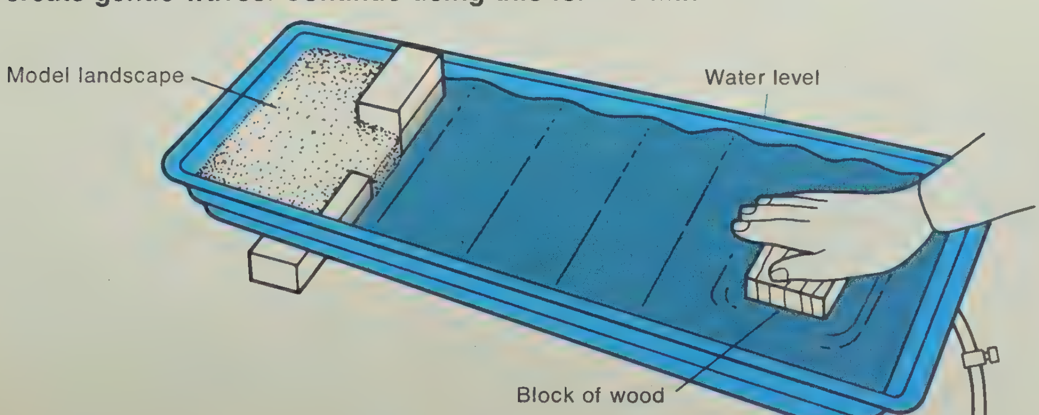
Changes of tide do affect the coastal landscape. You can observe this on a model landscape. To get started, obtain two plaster blocks (one larger than the other), some of the sand-silt mixture, a block of wood, and a stream table. You will use the sand-silt mixture and plaster blocks to build your own landscape.

The function of the plaster blocks in Activities 9-5 through 9-7 is as a means of noting the water level. The erosion will occur in the sand-silt mixture.

ACTIVITY 9-5. Pack your sand-silt mixture at one end of the stream table. Place the two plaster blocks into the sand, as shown. Raise this landscape end of your stream table with a block of wood or other support. Then fill the other end with water until it just covers the smaller of the two plaster blocks.

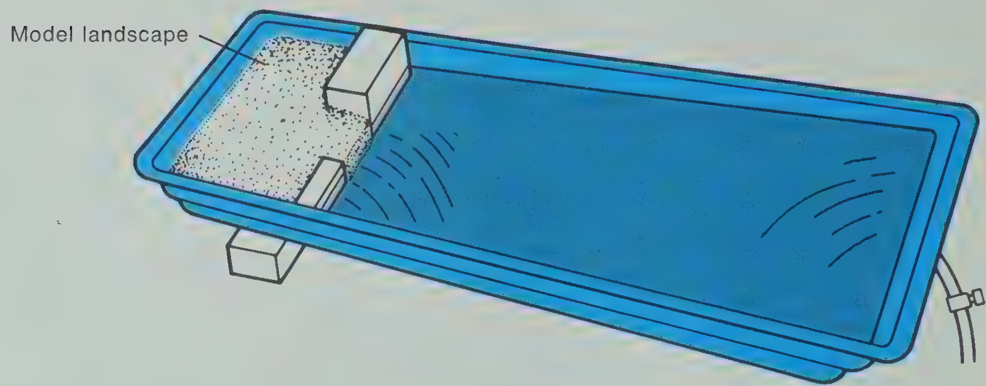


ACTIVITY 9-6. Place the block of wood in the stream table at the opposite end from your model landscape. Push down gently on the wood with the palm of your hand and then quickly lift your hand. Do this about every 5 sec, and you will create gentle waves. Continue doing this for 4–5 min.



□ **9-8.** Where (at what height) does most of the erosion take place?

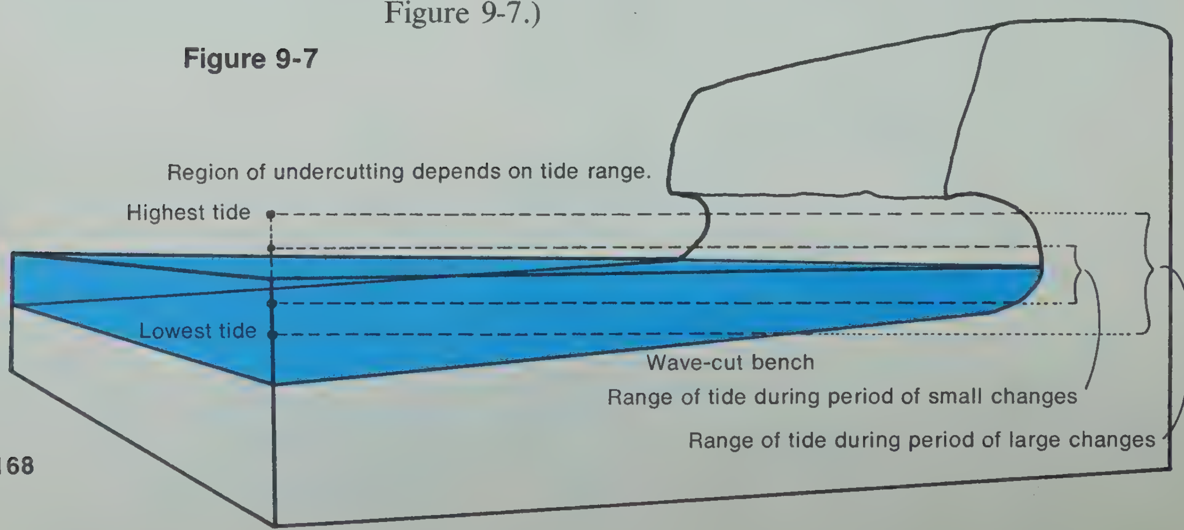
ACTIVITY 9-7. Let the water out through the drainage hole until only the lower half of the smaller plaster block is covered with water. Then repeat the wave action to see how a change in sea level can affect the landscape.



□ **9-9.** How does the change in sea level affect the landscape?

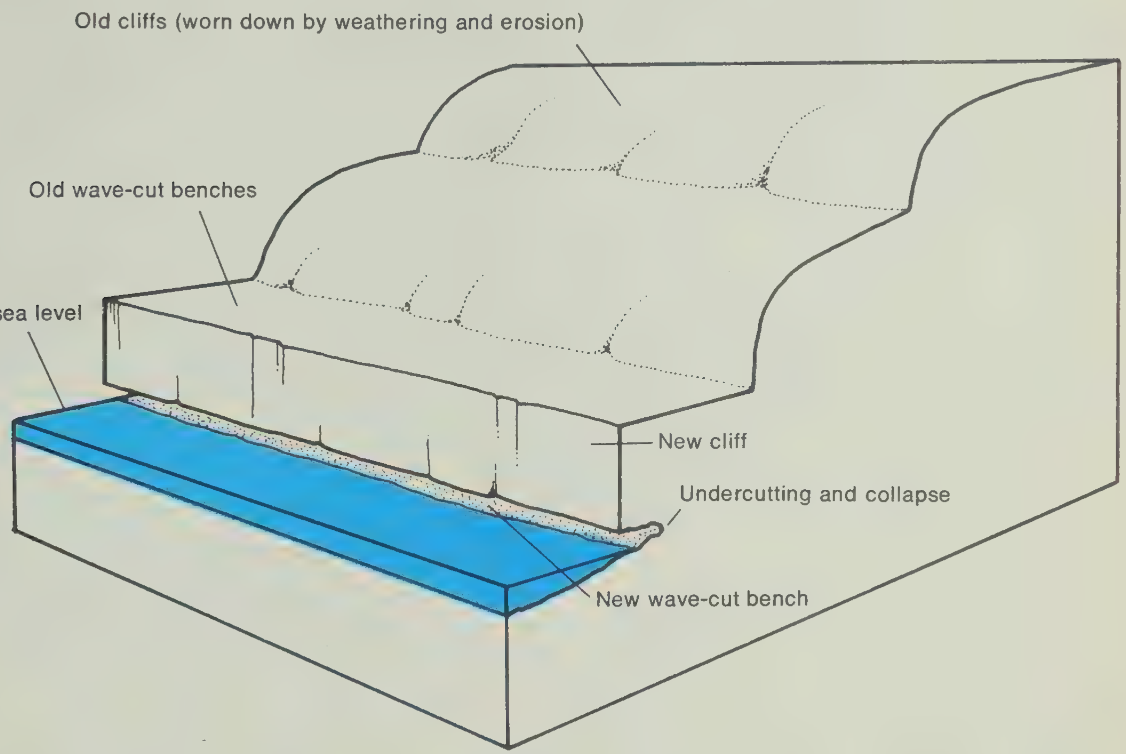
As you have seen, most erosion takes place at sea level. But sea level varies with the tides. This means that wave action will cause undercutting at more than one height on the face of a cliff. If there is a large difference between low tide and high tide, a wide strip is exposed to erosion. If there is a small difference between low tide and high tide, a narrow strip is exposed to erosion. In both cases, erosion produces a formation known as a *wave-cut bench*. (See Figure 9-7.)

Figure 9-7



The water level midway between low tide and high tide is called the *average,* or *mean, sea level.* If the average sea level drops, erosion starts to occur at a different part of the cliff. Then a new wave-cut bench starts forming, as shown in Figure 9-8. Old wave-cut benches can be recognized on many shorelines and are evidence of changes in sea level.

Figure 9-8



Before going on, do Self-Evaluation 9 in your Record Book.

Excursion 9-1
Building Seashores

PURPOSE

To investigate longshore drift caused by waves and to see how the shifting of the sand can be retarded.

EQUIPMENT

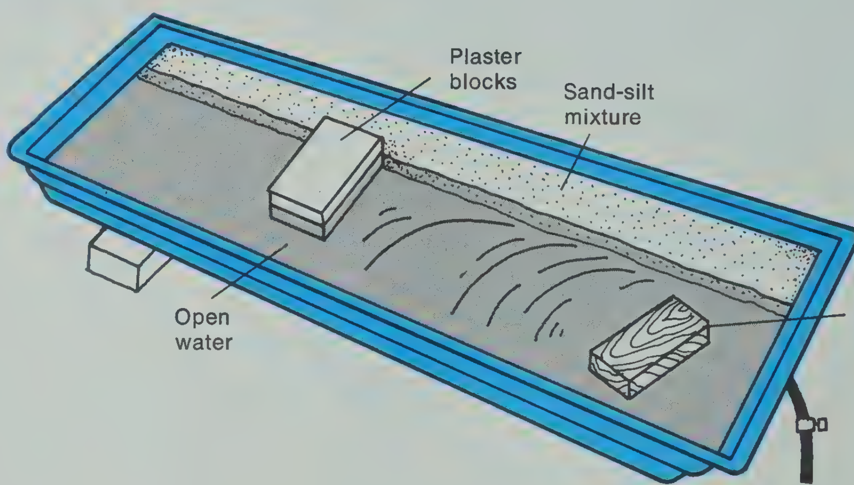
1 complete stream table
1 wooden block
2 large plaster blocks

MAJOR POINTS

1. An obstruction placed at right angles to the beach can retard longshore drift.
2. Piling up of sand by an obstruction can change the shape of the beach.

A beach can be built by hauling sand to the water's edge and dumping it in. This kind of beach usually washes away. It is easier to create a situation in which the beach will "build itself." This kind of beach will last longer.

ACTIVITY 1. Get 2 plaster blocks of the same size. Put one on top of the other and set them at right angles to the beach, as shown. The top block must be above water. Place a block of wood in the water at an angle to the shore. Press down on it once every 5 sec for 3–5 min. This should create a longshore drift.



☐ **1.** Where does sand build up in your stream table?

The overhead view in Figure 1 shows how the waves are bent (refracted) as they reach the plaster blocks. This causes sand to build up, as shown. Boat ramps, sea walls, and jetties have much the same effect and may actually cause the shape of the coast to change. A jetty at Panama City, Florida, is shown in Figure 2.

☐ **2.** Where is sand building up in Figure 2? (Use the results of Activity 1 in making this prediction.)

Along the southeastern coast of Florida, the prevailing breezes are from the southeast; so waves hit the sand beaches at an angle, as they do in these activities. Many structures, called groins, have been built perpendicular to the shoreline to halt longshore drift and maintain the beaches.

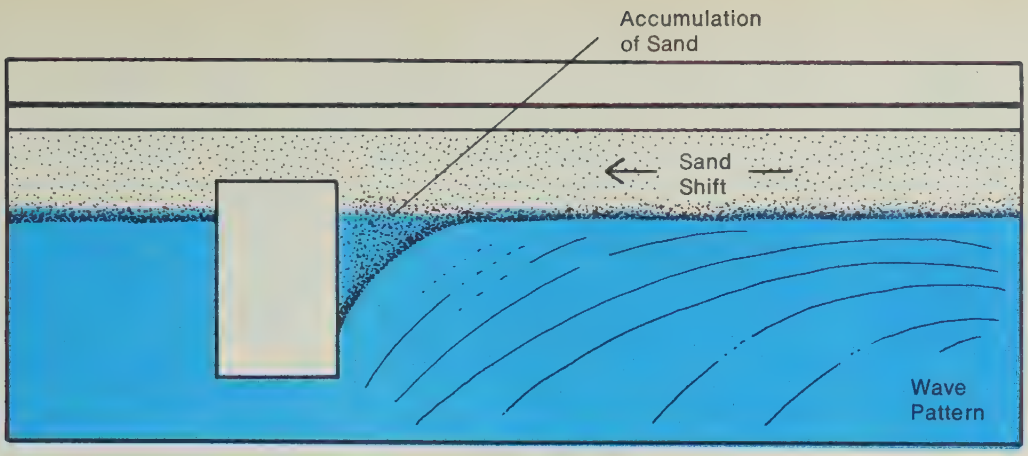


Figure 1

Figure 2

You have already seen many references to *sea level*. Along the coast, major landscape changes are related to sea level. Even the heights of mountains are given in terms of "metres above sea level." It is all very well to talk about sea level, but how can it be measured?

If you observe boats tied to a dock over a period of days, weeks, or months, you will realize that sea level just isn't level! Tides cause day-to-day, week-to-week, and month-to-month variations. Waves can cause minute-to-minute changes. You even get a slightly different view of sea level if you are in a boat looking at the land.

Excursion 9-2
Measuring Sea Level

PURPOSE

To investigate the meaning of the term *sea level*.

EQUIPMENT

None

MAJOR POINTS

1. The actual level of the sea changes all the time for many reasons.
2. A measuring instrument called a tide gauge can be used for measuring (operationally defining) and recording sea level.
3. Mean sea level is the average value between high water and low water.
4. Mean sea level differs at various places on the United States coast. One place can arbitrarily be chosen as the zero point for purposes of comparison.

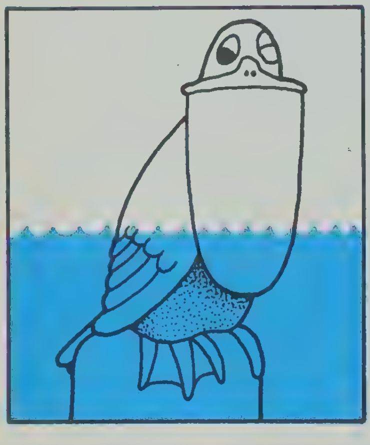
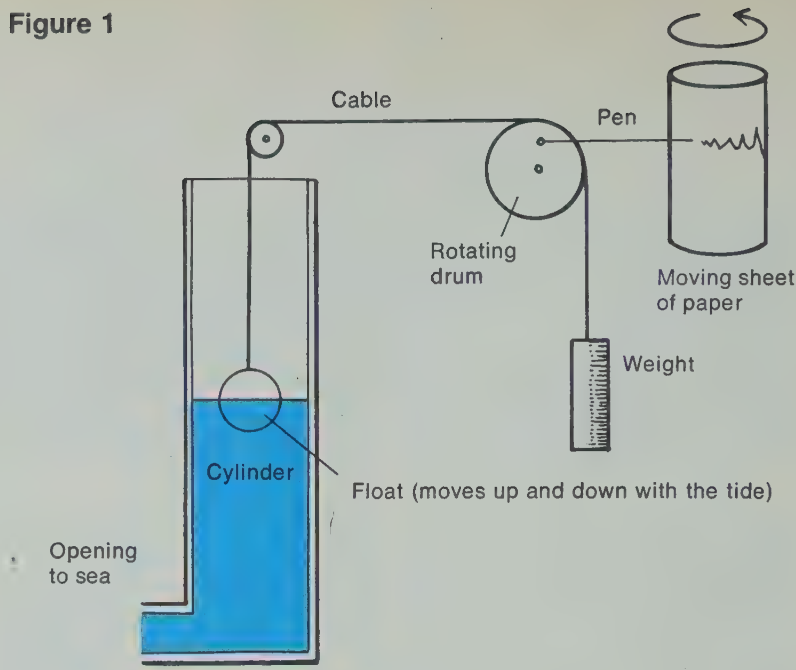


Figure 2 is given only as an example of daily changes in sea level. This chart would differ for just about every tide station in the world. Some stations located on the open Atlantic or Pacific Ocean (not in a bay, on the Gulf, etc.) would show two high and two low tides every 24 hours and 51 minutes, but the respective high and low measurements would be different in amount and in the time they occurred for each of the stations. For stations located on the Gulf of Mexico and on bays and inlets, so many different factors affect the tides (there are said to be 26 factors) that the chart may in some cases show only one high and one low in a 24-hour period.

Figure 1



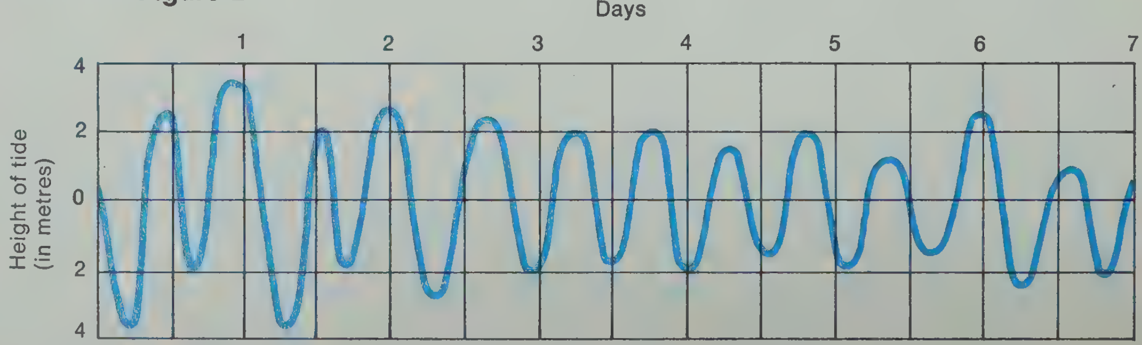
The measurement of sea level is no easy task. Usually a measuring instrument called a *tide gauge* (Figure 1) is installed at the end of a pier that stretches far out into the sea.

A tide gauge has a cylinder with a small opening that allows water to enter. The cylinder is filled to different levels, depending on the tide. One common form of tide gauge has a float in the cylinder. As the float moves up and down with the tide, the attached cable turns a drum, which in turn makes a pen move on a sheet of paper.

The pen traces out records like that on the chart shown in Figure 2. The graph, developed over a period of time, shows the highest level reached by the tide, the lowest level, and all levels in between.

Use Figure 2 to answer the following questions.

Figure 2



☐ **1.** How many times does the tide change each day?

☐ **2.** Is the change in sea level the same each time?

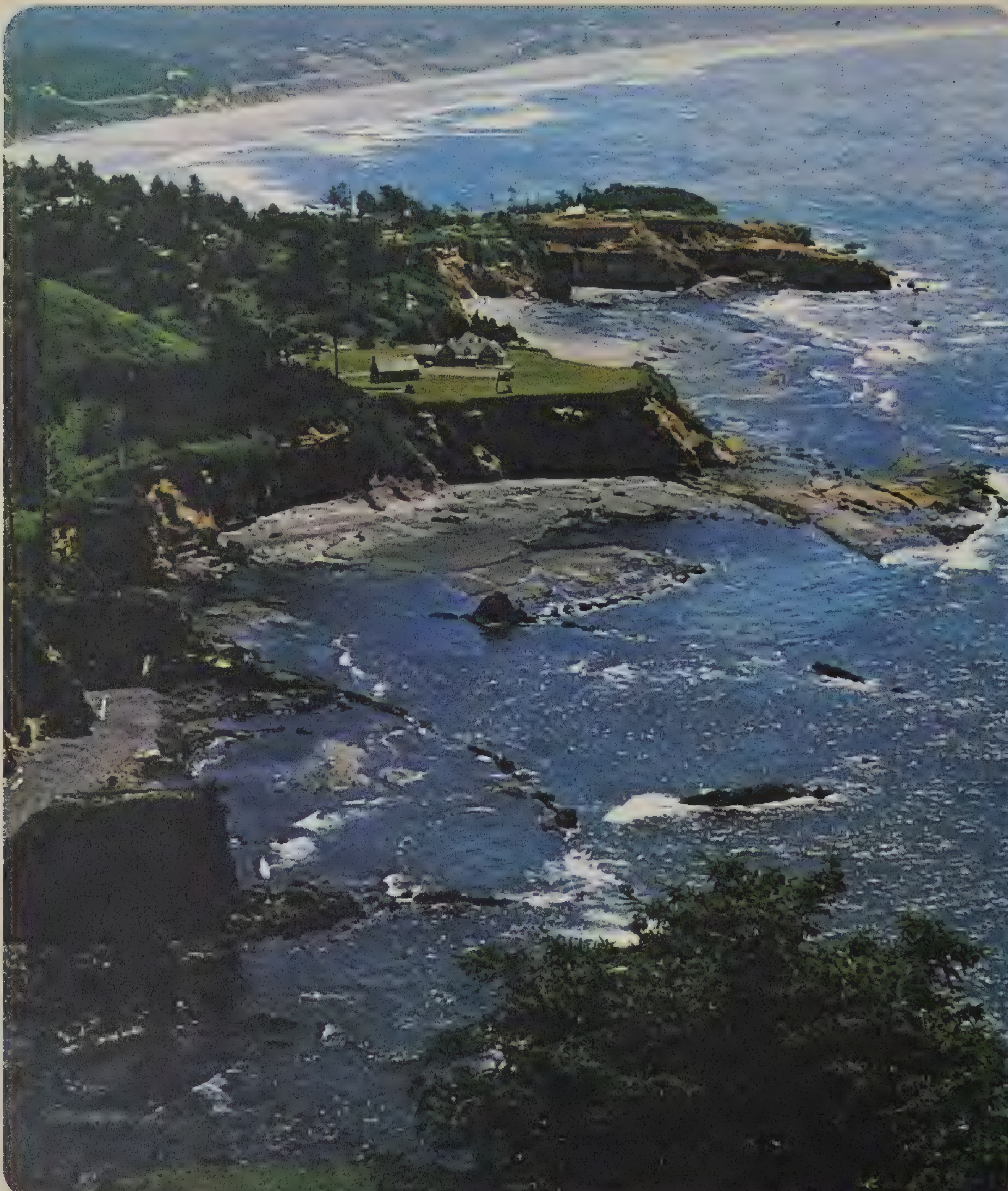
Mean sea level is an average value between high water and low water. From continuous readings like those in Figure 2, taken over a long period of time, a value for mean sea level can be calculated.

☐ **3.** Which value in Figure 2 would represent mean sea level?

Careful measurement has shown that the sea level is not the same at all places (see Figure 3). For example, if the sea level at St. Augustine, Florida, is taken as 0 cm, then the sea level at Portland, Maine, is about 38 cm higher; at San Diego, California, it is about 58 cm higher; and on the Oregon coast it is about 86 cm higher.

Charts from many different locations are used to calculate the mean sea level on which all measurements are based. The charts from all these tide stations are different. Scientists are not certain why there is a difference in sea level, but they think it is related to such variables as barometric pressure and water temperature.

Figure 3



Excursions 10-1 and 10-2 are keyed to this chapter.

Interpreting a Seacoast

10

EQUIPMENT

1 complete stream table
1 plaster block
1 wooden block
Sand-silt mixture

CHAPTER EMPHASIS

Many different forces are involved in the shaping of the shorelands. If these forces are well understood, they enable one to interpret the features of the shorelands and even to predict what may happen to them in the future.

Construction of the plaster block is described in the front of this Teacher's Edition, in the section entitled "Preparation of Equipment."

MAJOR POINTS

1. Depositional features, such as deltas, sandbars, and spits, generally result when the carrying capacity of water is reduced.
2. Deposits of sand piled up in the water are called sandbars; when they are connected to a tip of land and project out into the water, they are called spits.
3. A flooded ice-carved valley is called a fiord; a flooded river-carved valley is called an estuary.

The combined effect of ocean waves and tidal changes produces a great variety of seacoast landscapes. A shore of hard, resistant igneous rock will develop a different appearance than a shore of soft sedimentary rock. Seacoasts subjected to many storms will be eroded more rapidly than those subjected to few storms.

When a geologist tries to interpret a landscape, he or she looks for evidence of the changes that have been taking place. The geologist tries to figure out what caused the changes. Figure 10-1 contains evidence of a change that took thousands of years to happen. Can you spot the evidence?

☐ **10-1.** Describe how you think this coastline got to be the way it is. Here are some clues to help you. Notice the rocky

10-1. Students should be able to see that the flat area is an old wave-cut bench. Before the sea level dropped (or the land was uplifted), the waves eroded the shoreline to form the old sea cliffs and the flat bench in the foreground. At its present level, the sea is eroding new cliffs and forming another bench.

Figure 10-1

outcroppings in the foreground. Do they resemble the results of erosion you've been studying? What about the flat, gently sloping area in the center of Figure 10-1. What area of Figure 10-2 does it resemble? Examine that figure, which is an artist's sketch of the same area.

Figure 10-2

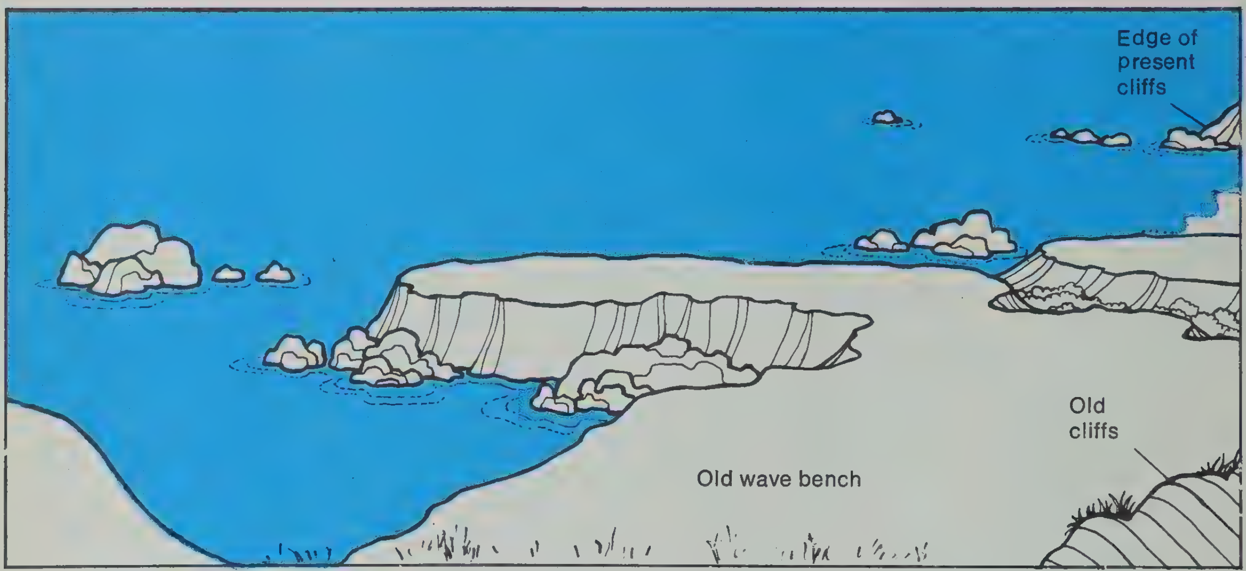
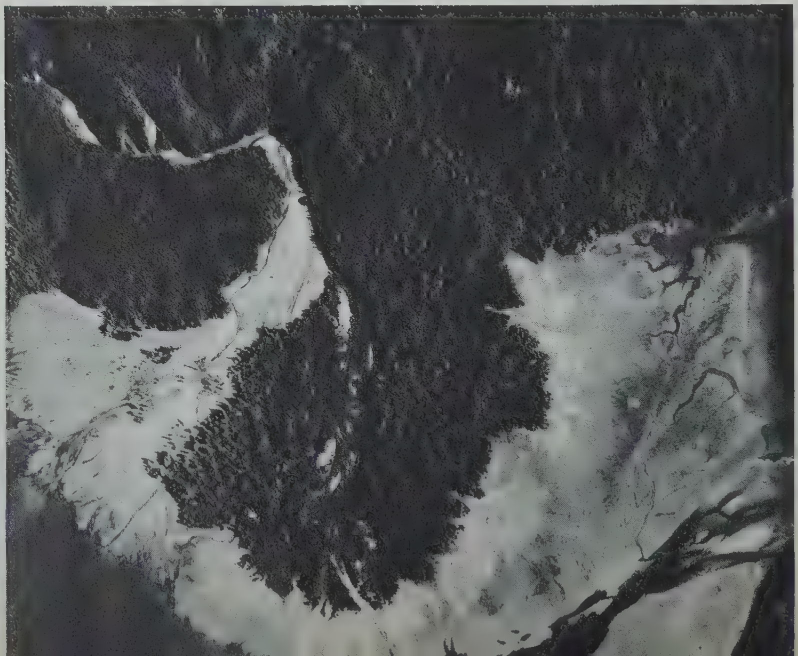


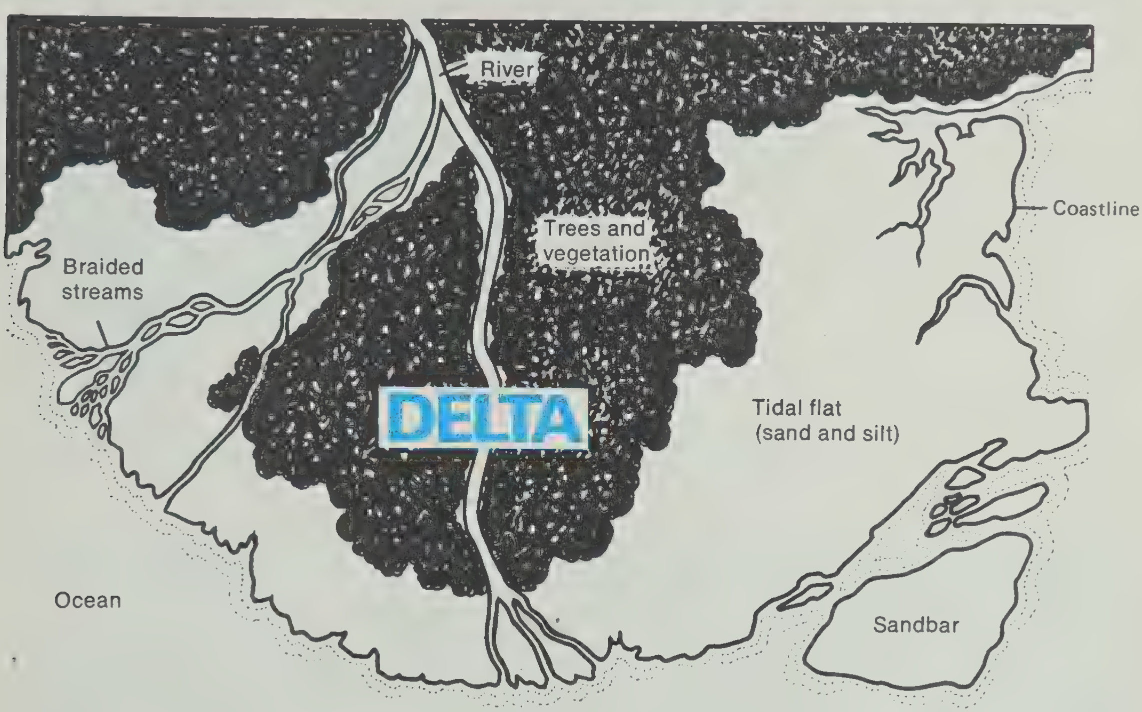
Figure 10-3 shows a view of a coastal feature from an angle you may or may not have seen before. It is an aerial shot of a delta. If you were to see this feature from ground

Figure 10-3



level, you would not be able to describe its shape unless you walked around the edges as well as across it. Figure 10-4 shows a diagram of the same region.

Figure 10-4



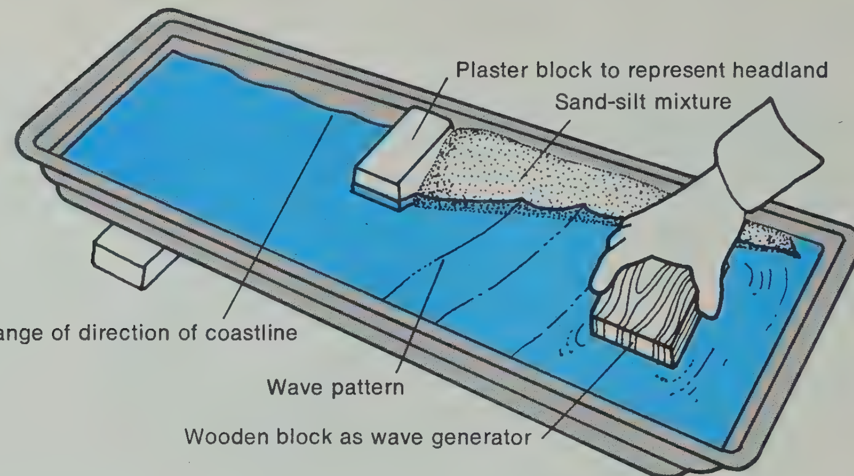
SANDBARS AND SPITS

Sandbars are deposits of sand that have built up as a result of currents or wave action. Long, narrow sandbars that project into the sea from the tips of headlands are called *sand spits*.

One way that spits form can be demonstrated in a stream table. Imagine a long coastline with angled waves drifting along a shallow shore. Can you predict what kind of beach will form where the coastline changes direction?

ACTIVITY 10-1. Pile up the sand-silt mixture to make a beach from one corner of the stream table to about the middle, as

shown. Then put in a plaster block to represent a rock headland. Pour in water to a depth of about 3 cm. Generate angled waves by pushing down every 3 sec on a wooden block. Do this for about 5 to 10 min.



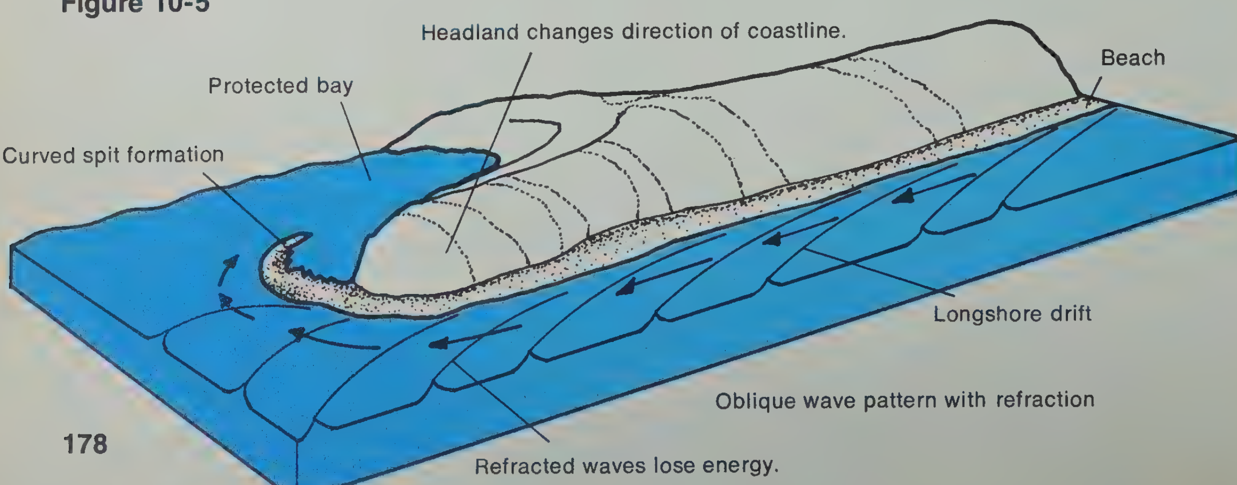
☐ **10-2.** What does the plaster block do to the waves—does it cause reflection, or refraction?

☐ **10-3.** Where does diffraction (curving of the waves) occur?

Not only is the energy of the waves reduced by hitting the headland, causing sand to be dropped, but the wave crests are bent by refraction and curved by diffraction, causing the sand deposit to be curved.

Your simulation should have produced a landform like that shown in Figure 10-5. Longshore drift shifts the sand along the coast to the headland. The energy of the waves is reduced as they swing around the headland, and the sand is deposited as a curved sandbar, or spit.

Figure 10-5



Sandbars can also be deposited off the mouths of rivers or in shallow water off a beach when currents carrying a load of sand are slowed down and lose energy.

Look back at Figures 10-3 and 10-4. Notice that a sandbar has formed on the right, and that the delta appears to have been growing faster on that side.

☐ **10-4.** According to your simulation activity, what might cause this growth at the delta? From which direction would you expect the waves to be coming? (The top of the map represents north.)

Ocean currents and wave action are at work along all coasts. Sometimes the currents flow parallel to the shore, and at other times they curve in or out. Usually they go in one general direction for months and months. Only occasionally do they change speed or direction. Waves, on the other hand, usually approach the shore at an angle that changes as the wind changes. (Sometimes the wind blows out to sea!)

Figure 10-6

This combination of currents and waves need not occur during the entire year for a sand spit to form.

EXCURSION

10-5. Waves striking the coast at an angle shift sand along the beach. Longshorecurrents also carry the sand along. At a headland, where the coastline changes direction, waves are refracted (bent) around the headland. They lose enough energy to deposit sand, which builds into a spit.

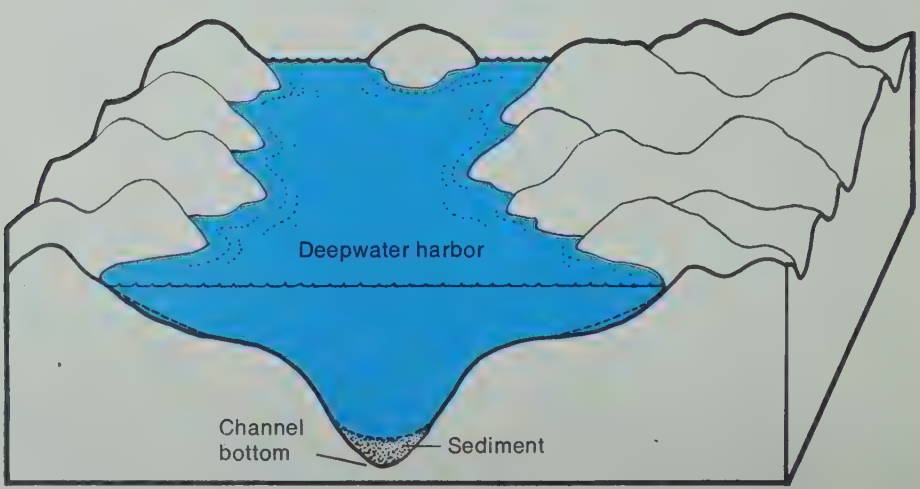
The *spit* shown in Figure 10-6 has built up where the ocean currents and the wave action together have deposited sand at the mouth of the river. Both the river and the ocean carry sediments. To find out how sand is formed and why it comes in so many forms and colors, do **Excursion 10-1,** "Where Does Beach Sand Come From?"

☐ **10-5.** How are wave direction and ocean currents involved in the shaping of the spit shown in Figure 10-6?

DEEPWATER HARBORS

Some rivers do not form deltas or spits where they empty into the sea. This is fortunate, because deep channels form the best harbors. Many of the world's deepwater harbors occupy flooded valleys. The Hudson River, Chesapeake Bay, Delaware Bay, San Francisco Bay, and the straits between British Columbia and the state of Washington are examples of waterways with deep channels. The channels are believed to be valleys carved by ancient rivers. It is believed the flooding of these rivers produced the dimensions of the present rivers and bays. Flooded river-carved valleys are called *estuaries*. Figure 10-7 shows the profile of an estuary.

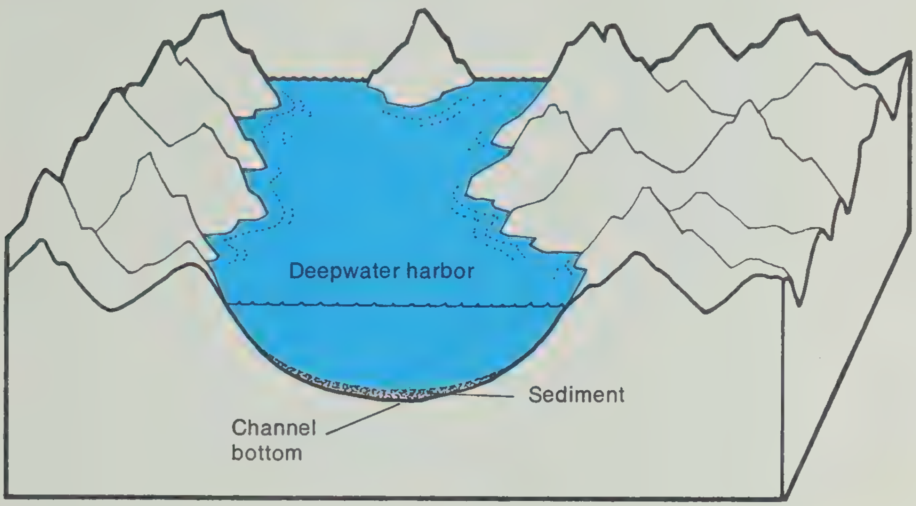
Figure 10-7



☐ **10-6.** Where does sediment collect in an estuary?

Not all deepwater harbors were formed from flooded river-carved valleys. Some are flooded ice-carved valleys, called *fiords*. (See Figure 10-8.)

Figure 10-8



☐ **10-7.** How is the bottom of the fiord different from the bottom of the estuary? Why is it different?

The fiord type of deepwater channel is found in mountainous regions where there is much evidence of glacial carvings. The wide, flat channel bottom of the fiord type of harbor is typical of valleys carved by glaciers. (Using depth soundings and aerial photography, scientists have discovered that the more V-shaped harbors reveal a river-valley pattern and shape.) Fiords can be quite long. Oslo, Norway, is located at one end of a fiord that is 145 kilometres long! If you are interested in learning more about fiords, look over **Excursion 10-2,** "The Formation of Fiords and Estuaries."

EXCURSION

SUMMARY

You've seen that many different forces are involved in the shaping of the shorelands. You should be able to interpret the main features of the shorelands and to predict what

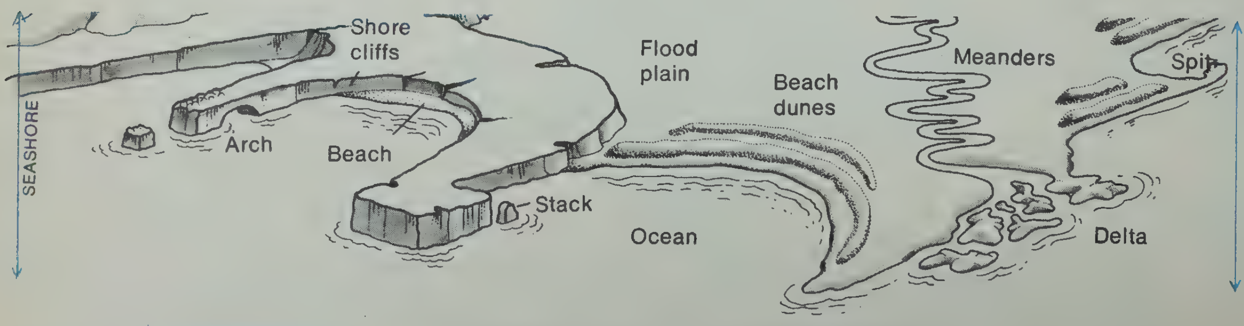
may happen to them in the future. The stretch of shoreline shown in Figure 10-9 has many of the features you studied. How many of them can you identify?

Figure 10-9

You can see that interpreting most of the landscape of shorelands is not hard when you know the forces that are involved. Look over Figure 10-10. You will recognize this drawing as part of Figure 2-4 from Chapter 2. If you can describe how the major features in the drawing were formed, you should be able to visit a beach and interpret many of the features you find there.

If you are located near a seashore, a field trip could be of tremendous value at this point. Students should be able to identify at least some of the features they have studied.

Figure 10-10



Before going on, do Self-Evaluation 10 in your Record Book.

Sand is simply any rock material that has been ground to a certain size. The grinding action is usually produced by the action of water or wind.

☐ **1.** Why is sand more likely to be formed along a seacoast than in a lake?

Beach sand is formed by the grinding action of rocks on each other. This occurs particularly when the water has high kinetic energy, either as a result of wave action or fast-flowing currents. Sand particles break off from rocks when waves batter the rocks against each other or against cliffs. The sand may be deposited on pocket beaches in the bays between rocky headlands. Or it may be swept away by wave action and washed up on a beach elsewhere. (Sand particles, because of their small size, can be carried great distances.)

Some of the sand on the Oregon beach shown in Figure 1 could have come from the grinding down of the neighboring rocky headland.

There are no rocky headlands within hundreds of kilometres of the Florida beach pictured in Figure 2. Part of this sand comes from broken shells and coral. Some of it may have been brought a long way by ocean currents.

Figure 1

The color and kind of sand formed depend on the kind of material that was ground down. In general, rocks made of hard minerals break down to sand. White sand like that

Excursion 10-1

Where Does Beach Sand Come From?

PURPOSE

To discuss the formation of various kinds of sand.

EQUIPMENT

None

MAJOR POINTS

1. Sand is rock material ground to a certain size by the action of wind or water.
2. In general, rocks made of hard minerals break down into sand.
3. The color and kind of sand formed depend on the kind of rock ground down. White sand is usually quartz; black sand is usually finely ground lava rock.
4. The color of beach sand may be altered by wastes, organic matter, or clay.

Figure 2

along the southeast coast usually comes from quartz. Darker sands are often formed by the breakdown of dark-colored rock. The black sands of Hawaii are composed of tiny grains broken from black lava rock. In some localities, the color of the beach may be altered by wastes, organic matter, or clay mixed with the sand.

☐ **2.** What determines the color of sand?

Excursion 10-2
The Formation of Fiords and Estuaries

PURPOSE

To discuss various theories of valley flooding.

EQUIPMENT

None

The large body of water shown in Figure 1 is *not* a lake system; it's a system of valleys flooded by the sea. The scene is in Alaska where Tracy Arm (in the foreground) empties into Holkam Bay. The bay, in turn, connects with the Pacific Ocean.

You may recognize features which indicate that the landscape was glacially carved. A possible explanation is that during the ice age, when these mountains were being carved to their present shape, great sheets of ice covered much of the Northern Hemisphere. With so much of the earth's water trapped in the form of glacial ice, the sea level would have been much lower then than now.

Figure 1

As the climate became warmer, the ice sheets melted back to their present positions over the North and South Poles. It has been estimated that the water released by the melting ice raised the sea level about 100 metres. This rise in sea level, according to one theory, caused the flooding of many valleys near the coasts.

A rise in sea level caused by melting ice is not the only possible way of forming estuaries and fiords. The same results would occur if earth movements caused the land to sink beneath the sea.

Figure 2 shows how a river valley can become an estuary. The end result is the same, regardless of whether the sea rose or the land sank or both those things occurred.

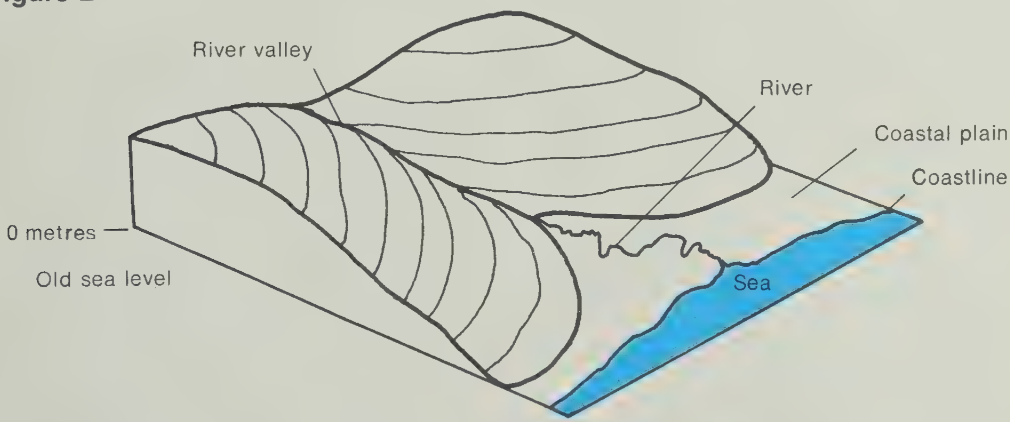
☐ **1.** Name two possible causes of valley flooding.

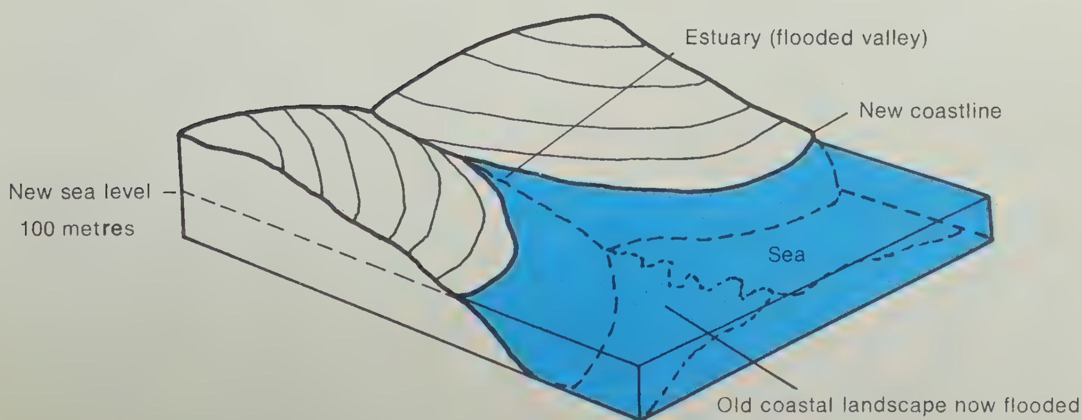
MAJOR POINTS

1. Melting of the glacial ice sheets may have raised sea level 100 metres.
2. The sinking of land beneath the sea could have the same flooding effect on a valley as a rise in sea level.

In the disastrous earthquake that hit Alaska in 1964, the land in several of the harbors sank enough to change the shape of the coastline considerably.

Figure 2





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EQUIPMENT

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Crusty Problems

Record Book

THE NATURAL WORLD MODULES / LEVEL 3

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ACKNOWLEDGMENT

The Natural World/3 is an adaptation, by Silver Burdett Company and the individuals listed on the previous page, of the materials produced originally by the Intermediate Science Curriculum Study (ISCS) and copyrighted by The Florida State University under the title of *Probing the Natural World.*

ISBN 0-382-04398-7

Contents

To the Student

This Record Book is where you should write your answers. Try to fill in the answer to each question as you come to it. If the lines are not long enough for your answers, use the margin, too.

Fill in the blank tables with the data from your experiments. And use the grids to plot your graphs. Naturally, the answers depend on what has come before in the particular chapter or excursion. Do your reading in the textbook and use this book only for writing down your answers.

Toward the end of this Record Book, you will find a set of Self-Evaluations for each chapter. Do these to check your progress. To check your answers to the Self-Evaluations, turn to the Self-Evaluation Answer Key in the back of this Record Book.

Answers provided are often completely dependent on local circumstances. Be quite flexible as you assist your students with their attempts to answer questions. Answers are hardly ever as important as the process that generates them.

Additional questions I have thought about:

1. ______

2. ______

3. ______

4. ______

5. ______

☐ **1-1.** If you were an observer from outer space, how would you describe the planet before you?

It is spherical with different-color surfaces, a lot of water, and white clouds covering large areas. The haze around it shows that it has an atmosphere. It seems to be magnetized, because it affects the magnetic instruments.

☐ **1-2.** List the important features you see in the photograph.

Solid areas of several different colors; large water areas; large areas of clouds; several large river channels (if close enough); shadows show mountains; thin halo shows an atmosphere.

☐ **1-3.** In the photograph, do you see any evidence of motion or change?

No

Chapter 1
A First Look at the Earth

☐ **1-4.** What would you say if asked the same question about Figure 1-2? If you decided that change is shown in the photograph, list the evidence you used to make that choice.

Yes. Smoke; material being thrown out; evidence of material thrown out in the past.

Activity 1-1. Use the map on the next page.

☐ **1-5.** What evidence is there that a powerful force was exerted on the rock shown in Figure 1-3?

Long, carved scratches or grooves suggesting something dragged across rock surface

☐ **1-6.** What can you tell about the direction the glacier must have moved to carve such grooves as in Figure 1-3?

The glacier must have moved parallel to the grooves. (This narrows possibilities down to two directions, but picture does not provide adequate clues as to which of the two.)

☐ **1-7.** Do you think the distribution of glacial drift and the location of glacial grooves provide evidence to support, or reject, the idea of continental drift? Explain your answer.

The evidence seems to support the idea of continental drift. In order for glacial grooves to have formed in the direction they are now found, they must have originated on the same landmass. The only other explanation—an implausible one—is that the glaciers came across the oceans.

EURASIA
INDIA
AUSTRALIA
ANTARCTICA
AFRICA
GREENLAND
SOUTH AMERICA
NORTH AMERICA

☐ **1-8.** If not, what other explanation can you make?

Something else besides glaciers made the grooves.

Excursion 1-1
Geologic Time

☐ **1.** If you plotted the last three events in Table 1 on the paper tape, could you tell them apart? Explain.

No. They would be represented by distances too small to be measured.

☐ **2.** According to the scale you used to plot time, how many years does the width of your pencil point represent?

About 200 000 years

2. There are roughly 5 pencil-point widths to 1 mm. Since 1 mm represents 0.001 billion years (1 000 000 years), 1 pencil-point width equals approximately 200 000 years.

☐ **3.** Is your age a significant part of geologic time? How about the age of the United States?

No

Excursion 1-2
Rock Layers, Fossils, and Continental Drift

☐ **1.** Can you match any rock layers shown in Figure 2?

Yes, they match by colors.

☐ **2.** Are the layers in rock sequence 1 in the same order as the layers in rock sequence 2?

No

☐ **3.** What else is different in the two sequences?

Sequence and thickness are different.

☐ **4.** What two clues indicate that land in two different parts of the world may have originally formed in the same place?

Answers will vary. (Students might suggest comparing layers for same order, composition, and fossils.)

☐ **5.** How can you explain the occurrence of similar rock layers and identical fossil plants on two different continents?

The continents may have been together when the layers formed.

Chapter 2
Other Views of the Earth

☐ **2-1.** To make sure you can read the table, determine the following for the first earthquake listed.

- **a.** Date earthquake occurred
- **b.** General location
- **c.** Depth (km)
- **d.** Latitude
- **e.** Longitude

a. Feb. 1, 1971; b. Turkey; c. 35 km; d. 37.2° N; e. 30.2° E

☐ **2-2.** What are the coordinates of point Z?

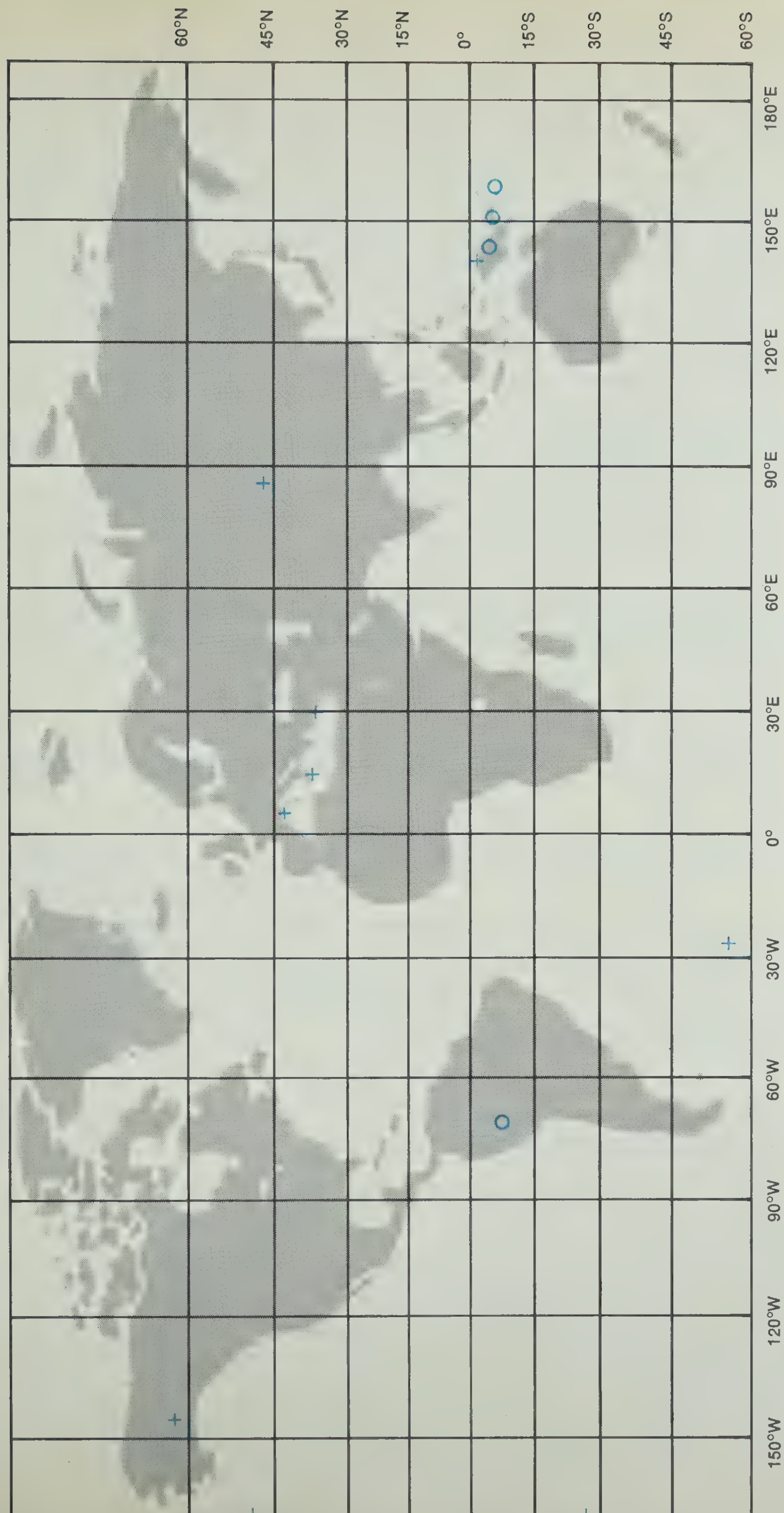
Latitude 15° N and longitude 120° W

☐ **2-3.** On the basis of the earthquakes you have just plotted, list the regional locations of the earthquakes.

Ring around the Pacific Ocean; Malay Peninsula; South Sea Islands and Japan; line through North and South Atlantic Ocean; Mediterranean through to South Asia

☐ **2-4.** Would you say that earthquakes are randomly distributed over your map, or are they concentrated in zones?

They are in zones.



Activity 2-1

Notice that two earthquakes recorded in Table 2–1 occur on the Aleutian Islands. Because these earthquakes are so close together, it is difficult to separate them. Therefore it is acceptable to indicate both with one mark on this map.

☐ **2-5.** Can you find any zones on your map where there are concentrations of shallow, intermediate, or deep earthquakes? If so, where?

Shallow—through the mid-Atlantic Ocean; intermediate—western coast of South America; deep—South Sea Islands

☐ **2-6.** In the region between South America and Africa, are the earthquakes shallow, intermediate, or deep?

Shallow

☐ **2-7.** How deep are the earthquakes that occur along the western coast of South America? (Give a range of depths.)

Intermediate—70 to 299 km

☐ **2-8.** Identify two other areas where intermediate and deep earthquakes occur.

Malay Peninsula, Japan, South Sea Islands

☐ **2-9.** Knowing that the crust spreads out from a ridge on either side, what can you say about the age of the rocks near the continents, compared with the age of the rocks near the ridge?

The rocks near the continents are older.

☐ **2-10.** How are earthquakes produced at the mid-ocean ridge, according to the plate theory of the earth's crust?

Earthquakes are produced when plates of the earth's crust separate or collide.

Excursion 2-1
Latitude and Longitude

☐ **1.** In what two ways are longitude lines different from latitude lines?

Longitude lines all converge at the Poles, but latitude lines are parallel.

Longitude lines run vertically, but latitude lines run horizontally.

☐ **2.** Which lines are parallel to each other?

Latitude lines are parallel.

☐ **3.** Using the numbers shown in Figure 3, what is the position of New York City?

a. Latitude (parallel) 40° 43′ N

b. Longitude (long slice) 74° 00′ W

☐ **4.** Latitude and longitude may be used on flat maps as well as globes. What would be the position of City Hall in New York City on the map in Figure 4?

a. Latitude 40° 43′ N

b. Longitude 74° 00′ W

☐ **5.** What is the latitude of the equator?

0°

☐ **6.** What is the longitude of the prime meridian?

0°

☐ **7.** Is the longitude of New York City (Figure 3) east, or west, of the prime meridian?

West

☐ **8.** Latitude lines are labelled either north or south. In relation to what line are they measured?

The equator

☐ **9.** Longitude lines are labelled either east or west. In relation to what line are they measured?

The prime meridian

Chapter 3
Mountain Materials

☐ **3-1.** Which photograph in Figure 3-3 shows a rock that obviously has more than one material?

The photograph on the right

☐ **3-2.** Which photograph in Figure 3-4 appears to have noninterlocking grains? Explain your choice.

The photograph on the left. Different solids seem to be cemented together by a reddish-brown glue.

Table 3-1

Sample Number of Color	Number of Components	Texture		Arrangement	
		Interlocking	Noninterlocking	Random	Oriented
05					
06					
08					
12					
13					
17					

☐ **3-3.** True or false: A single piece of rock may contain more than one mineral.

True

☐ **3-4.** Which samples are noninterlocking?

Conglomerate (13) and limestone (17)

☐ **3-5.** What is the purpose of this third experiment?

The third experiment is called a control. The purpose of the control is to see if anything happens in the absence of the ferrous sulfate and the ferrous ammonium sulfate. If nothing happens to the control, it can be assumed that the ferrous sulfate and the ferrous ammonium sulfate are responsible for the observed effects.

☐ **3-6.** What do you notice?

The sand was somewhat cemented together, and the color had changed in the two dishes to which the chemicals had been added. There was no change in the sand in the control dish.

☐ **3-7.** What kind of rock is volcanic rock?

Igneous

☐ **3-8.** What differences do you observe between the substances cooled by pouring down the glass and the substances cooled by pouring them into a cup surrounded by sand?

Crystals formed by rapid cooling on the glass are much smaller.

☐ **3-9.** Which rock samples appear to be igneous?

Pink granite (06) and gabbro (08)

☐ **3-10.** What differences can you see in the crystals in the igneous rock samples?

The crystals are of different sizes, colors, and compositions.

☐ **3-11.** Can you predict which rock is from an intrusion?

Yes, pink granite

☐ **3-12.** Look back again at the eroding rock in Figure 3-5. Where in the rock cycle does this picture fit?

Erosion

☐ **3-13.** From where to where would an arrow have to be drawn in Figure 3-7 to show what the river is doing to the rock?

From sedimentary rock to erosion

☐ **3-14.** What kind of rocks would you find if you visited the Appalachian Mountains?

Possibly all three kinds. The valley and ridges consist of sedimentary rock; intrusions of igneous rock occur along the Blue Ridge; some of the uplifted rock may have been changed to metamorphic.

☐ **3-15.** Are there any mountains in your state? (If not, go on to question 3-16.) What is the name of these mountains? What kind of rocks are found in them?

(Answers will vary with locations.)

☐ **3-16.** If your response to 3-15 was No, where are the closest mountains?

(Answers will vary with locations.)

☐ **3-17.** What kinds of rocks would you find there?

(Answers will vary with locations.)

Excursion 3-1
Identifying Rock-forming Minerals

☐ **1.** Is mineral sample 23 harder, or softer, than glass?

Harder than glass

☐ **2.** What kind of luster does mineral sample 23 have?

Nonmetallic luster

MINERAL CLASSIFICATION CHART

			Special Properties	Name	Sample Number
Nonmetallic luster	Harder than glass	Cleavage	2 directions of cleavage; pink white	Microcline feldspar	(23)
			2 directions of cleavage; white, blue-gray, striations (lines) on some cleavage planes	Plagioclase feldspar	(24)
		No cleavage	Red, brown, or yellow	Garnet	(26)
			Olivine green; commonly in small glassy grains	Olivine	(31)
			Transparent, milky-white	Quartz	(32)
	Softer than glass	Cleavage	Brown to black; perfect cleavage producing thin elastic sheets	Biotite mica	(29)
			3 cleavage directions—surfaces look like this □; colorless, white; effervesces in HCl	Calcite	(22)
			Perfect cleavage, producing thin elastic sheets	Muscovite mica	(30)
			Dark-green to black; 2 cleavage directions	Hornblende and Augite	(28) and (21)
Metallic luster	Harder than glass	Cleavage	Brass-yellow color; cubes	Pyrite	(33)
		No cleavage	Red	Hematite	(27)
	Softer than glass	Cleavage	Heavy; silver-gray color; little cubes	Galena	(25)

Excursion 3-2

The Formation of Layered Sediments

☐ **1.** What common feature do the three photographs have?

They all show layered material.

☐ **2.** Describe what you see in that test tube.

The different materials settle out in layers. The larger, heavier material settles out first to the bottom.

☐ **3.** How could this process of particles settling in water explain layers like those in the photographs on page 48?

Sediments settle out of water in locations where the moving water carrying them slows down. This is repeated several times.

☐ **4.** What evidence would you need about the rocks in the photographs to confirm that this process caused the layers to form?

Examine samples for larger particles at the base of the layers and lighter particles at the top of the layers.

☐ **5.** What happened when you added hydrochloric acid to the particles?

The hydrochloric acid reacted with the particles to give off gas.

☐ **6.** How can you tell limestone, sandstone, and shale apart?

Hydrochloric acid reacts actively with limestone, but not with sandstone or shale.

☐ **7.** What do you notice about the rate of settling of the different-sized particles?

The larger, heavier particles settle out first.

Excursion 3-3
Classifying Rocks

Table 1

Rock sample	Predicted origin	
	Molten/hardened	Sediment/hardened
05 (gneiss)		
06 (pink granite)		
07 (gray granite)		
08 (gabbro)		
09 (basalt)		
10 (rhyolite)		
11 (obsidian)		
12 (marble)		
13 (conglomerate)		
14 (pumice)		
15 (quartzite)		
16 (shale)		
17 (limestone)		
18 (slate)		
19 (sandstone)		
20 (schist)		

☐ **1.** Study each of the five items in the Texture Test. What kind of rocks would each item apply to?

(Answers will vary. A thorough response could include the following: interlocking components—not a mineral and not sedimentary; noninterlocking components—sedimentary rock; glassy looking—igneous, possibly metamorphic; looks frothy with lots of holes—igneous; and fine-grained seeming to lack minerals—probably metamorphic if crystals are all of the same kind.)

Table 2

Rock Sample (no.)	1. Interlocking minerals?		2. Same mineral?		4. Evenly distributed?	
	Yes	No	Yes	No	Yes	No

☐ **2.** What does the presence of fossils tell you about the history of a rock?

Fossils can tell you something about the geologic period and the location of the formation of the rock.

7. Frothy (with holes)?		**9.** Glassy		**11.** Visible particles?		**13.** Slatelike sheets?	
Yes	No	Yes	No	Yes	No	Yes	No

Excursion 3-4
A Field Trip in the Classroom

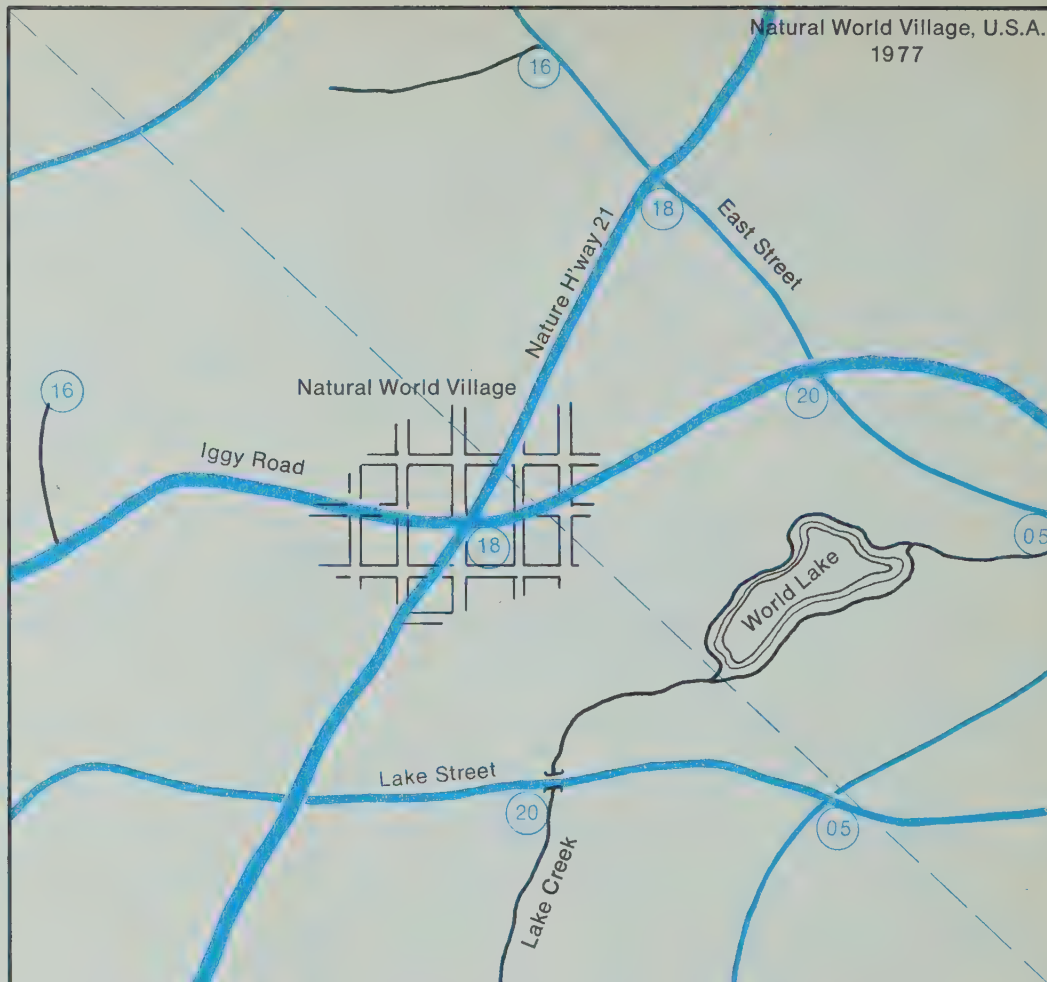


Figure 1

☐ **1.** If you start from the upper left-hand corner and move along the line to the lower right, what major differences among the rocks do you note?

The rock types change from sedimentary (shale) to forms of metamorphic (slate, schist, gneiss) as you go toward the lower right.

☐ **2.** What differences do you note in the size of the minerals in the four rocks?

The size of the minerals will get larger as you progress downward to the right.

☐ **3.** What differences do you note in the arrangement of the minerals in the four rocks?

The arrangement of minerals will be toward more pronounced banding, from samples 16 to 18 to 20 to 05.

☐ **4.** Which region on the map do you think was subjected to the highest temperatures and pressures?

The lower right corner

Chapter 4
Shaping Up Mountains

☐ **4-1.** What evidence is there that this volcano is active?

The rising melted rock, the lava pouring down the sides of the mountain, the lava being thrown into the air, the rising columns of smoke and fire.

☐ **4-2.** How do you think the Mono craters are formed?

They are formed by volcanic action.

☐ **4-3.** Based on your knowledge of rocks, what clue does the texture of the rock give you as to the origin of the rock?

It is an igneous rock (rhyolite). The fine-grained nature of the rock suggests that it was formed from molten rock at the surface of the earth.

☐ **4-4.** What evidence is there that the mountain in Figure 4-3 is volcanic?

The shape is typical of a volcano.

☐ **4-5.** Why is the igneous rock from fissures fine-grained?

Igneous rock formed in fissures tends to be fine-grained because it cools rapidly.

☐ **4-6.** What type of rock is found in lava flows and sills? What difference would you expect to find in the grain size of rock samples from each?

Igneous rock. The crystals are larger in sills because of the slower cooling rate beneath the earth's surface. Lava flows cool rapidly because they are exposed to the air; hence the crystals are smaller.

☐ **4-7.** What do the differences in these rocks tell you about how and where the Stone Mountain samples were formed?

The rocks (gray granite) are igneous, but they were formed deep beneath the surface. They cooled more slowly and under higher pressure than the igneous rocks that formed on the surface of the Mono craters.

☐ **4-8.** Which mountains appear older—those shown in Figure 4-7 or those in Figure 4-8? Why?

The mountains in Figure 4-8 appear older. The smooth surfaces show that they have worn down considerably from erosion and weathering.

☐ **4-9.** What is the most obvious difference between new and old mountains?

Worn, rounded surfaces characterize old mountains and jagged, rough surfaces characterize new mountains.

☐ **4-10.** What happens to the clay model?

Folds develop.

☐ **4-11.** What evidence do you see of folding in Figure 4-12?

In a side view, individual "ripples" or "folds" are apparent in the colored clay layers. The top view shows strips or bands formed by the folded layers.

☐ **4-12.** Sea shells are commonly found in rock more than 2 000 metres above sea level in the Appalachian Mountains. How can you explain this?

These sea shells were once buried in sediment under the sea. The sediment hardened into rock, and this rock, containing the shells, was uplifted and formed the mountain.

☐ **4-13.** Choose one kind of mountain from the table and explain its formation on the basis of one of the models you have studied.

(Answers will vary according to the model used. A model of the collision of crustal plates would explain faulting and folding.)

Excursion 4-1
Igneous Intrusions

☐ **1.** Which kind of igneous intrusion do you think the dark bands in the photograph are?

A sill

☐ **2.** Is the vertical strip of rock in Figure 2 a sill, or a dike? Explain your answer.

A dike—the molten rock appears to be trapped in a vertical layer.

☐ **3.** Would you expect the strip of rock in the photograph to be igneous, or sedimentary, rock? Explain your answer.

Igneous rock—it appears to have been formed by molten rock forced into a vertical crack across several layers of rock.

☐ **4.** If you compared rock samples that came from a sill, a lava flow, and a dome, what differences might you expect to see?

The rock sample from the lava flow would contain the smallest crystals, the rock from the sill would have larger crystals, and the rock from the dome would probably have the largest crystals of the three. This is a direct result of the cooling time during formation of the rock. Lava flows occur on the surface of the earth and cool quite rapidly. Cooling within

the earth's crust occurs more slowly. Since domes are formed deep in the earth's crust, they are characterized by rock with very large crystals.

Chapter 5

Carving Mountains with Ice

☐ **5-1.** What evidence is there in Figure 5-1 that the glacier is *not* advancing? (Hint: Compare the size of the glacier with the area that has been carved out.)

The glacier seems to be melting and shrinking in size. The area carved out is much larger than the glacier material shown.

☐ **5-2.** Explain how the rock shown in Figure 5-2 moves down the glacier even though the foot of the glacier remains at the same point.

The buildup of ice at the head of a glacier is independent of conditions at the foot. The rock will move downhill as long as the head of the glacier grows and the ice advances.

☐ **5-3.** What are the causes of a glacier's advance?

A glacier advances mainly because the rate of formation of ice at its head is greater than the rate of melting.

☐ **5-4.** How is a tarn different from a cirque?

A tarn is a lake formed in a cirque.

☐ **5-5.** What features of the horn shown in Figure 5-7 suggest glaciers were involved in shaping it?

Several cirques

☐ **5-6.** Why, do you think, does the main glacier carve a deeper valley than its tributary glaciers?

The main glacier contains more ice.

Excursion 5-1
Snow to Ice

☐ **1.** Why is the top surface of a glacier much lighter than the bottom surface?

The top surface has unpacked snow on it. At the bottom of the glacier the weight of the materials above it packs the snow, causing it to recrystallize and form ice crystals. At depths of more than 30 metres, the pressure is so great that solid ice forms.

Chapter 6
The Midlands A Pathway to the Sea

☐ **6-1.** Look at Figure 6-2. Which occupies the greater land area, the midlands or the remaining regions?

More midlands

☐ **6-2.** Which has more areas of high elevation, the eastern or western United States?

Western United States

☐ **6-3.** Compare the elevation map (Figure 6-4) with the map of the river system (Figure 6-3). In general, how does the elevation where rivers originate compare with the elevation downstream?

The elevation at river's source is higher.

☐ **6-4.** Compare the elevation map (Figure 6-4) with the map of the midlands (Figure 6-2). Do the midlands all have the same general elevation?

No

☐ **6-5.** When does a river have its greatest kinetic energy? When does it have its greatest potential energy?

A river has high kinetic energy when it is flowing rapidly; it has high potential energy when it is at a high elevation.

☐ **6-6.** What makes the water slow down at the base of the falls?

The water loses kinetic energy as it crashes into the base of the falls.

Table 6-1

	Slope (in cm)	Rate of flow into trough (in ml/sec)	Trough bed	Speed (in cm/sec)
Trial 1	4	10	Sand-silt	
Trial 2	8	10	Sand-silt	
Trial 3	12	10	Sand-silt	
Trial 4	4	20	Sand-silt	
Trial 5	4	10	Gravel over sand-silt	

☐ **6-7.** What three variables affect how fast water flows down the trough?

The slope of the stream, the amount of water, and the roughness of the bed

☐ **6-8.** What happens to the kinetic energy of river water as it travels over a steep slope?

It increases.

☐ **6-9.** What happens to the kinetic energy of river water as it encounters gravel or rocks?

It decreases.

Excursion 6-1
Effects of Obstacles upon Direction of Stream Flow

☐ **1.** The river in Figure 2 is braided, too. What caused the splitting this time?

Gravel or small rocks

Chapter 7
Water at Work

☐ **7-1.** As the stream slows down (loses kinetic energy), what happens to the materials it carries?

They are deposited.

☐ **7-2.** As the stream speeds up (gains kinetic energy), what happens to the amount of material it carries?

The amount increases.

☐ **7-3.** Take a look at Figure 7-1. Where would the stream be moving rapidly? Where would it be moving slowly?

It would be moving rapidly in the mountains and slowly below the mountains.

☐ **7-4.** When the plaster becomes exposed, what happens to the rate of erosion upstream and downstream from it?

Downstream a waterfall forms, with erosion continuing below the falls.

Erosion slows down above the falls.

☐ **7-5.** If you have done Part II, on mountains, you should be able to make a good guess as to which rock type is at the top of a waterfall. Would it be igneous, metamorphic, or sedimentary?

Igneous, or metamorphic

☐ **7-6.** What happens to the sand as water runs off the hill?

Gullies are formed.

☐ **7-7.** Why do gullies begin to form?

As the water speeds up going down the slope, it increases erosion and the gullies it forms. Once formed, the gullies continue to lengthen as the water flows to the nearest lower level.

☐ **7-8.** How much headward erosion occurs with Niagara Falls each year?

1.5 metres

☐ **7-9.** Why does so much broken rock collect at the base of the falls?

The water is not moving fast enough to carry the large rocks off.

☐ **7-10.** What happens to the load of particles being carried downstream as the water slows down? (Hint: See your results in Activity 7-2.)

The particles are deposited as the water slows down. The heaviest ones are deposited first. The light ones are deposited as the water slows down even more.

☐ **7-11.** What factors cause streams of water to slow down?

Change of slope and width of stream channel

☐ **7-12.** Look at Figure 7-8. What evidence is there that the water flows faster on the outside of the turn?

Sand and silt are deposited on the inside of the bend.

☐ **7-13.** Which side of the river is being eroded more? Where do you think this eroded material is going?

The outside of the bend erodes more, with the eroded material being deposited farther downstream.

☐ **7-14.** Why do such formations occur only at the mouth of streams or rivers?

The mouth is where the water can no longer flow downhill. As the water flow stops, or slows down, the remaining sediments it carries are deposited.

☐ **7-15.** In what way is a stream as it reaches the foot of a slope similar to a river as it meets the sea?

They are both at a point where the water slows down abruptly.

Excursion 7-1
Gullies and Canyons— A Comparison

☐ **1.** What similarities do you see between the two figures?

Both figures show cuts where water has eroded material away.

☐ **2.** As you look at the differences, do you think a gully can become a canyon? Explain.

No. The characteristics of canyons and gullies are different. (However, there is much similarity in the way they form.)

Excursion 7-2
Action of Water Moving in a Curved Path

☐ **1.** Where in the beaker did the sand pile up? Why did this happen? A simple experiment can help you decide.

In the center (Answers may vary. Students will be able to understand the principle involved after they have completed the next activity.)

☐ **2.** Which letter moves fastest?

A

☐ **3.** Is the letter that moves slowest near the center, or near the rim, of the disk?

Near the center

☐ **4.** In your stream table, on which side of the bend does the water move faster? How do you know?

The outside, because that is the area where erosion is the greatest

Excursion 7-3
Delta Formation and Changes in Sea Level

☐ **1.** What size particles travel farthest into the reservoir? Which travel the shortest distance?

The small-size particles travel farthest. The large-size particles travel the shortest distance.

☐ **2.** Where was the sand deposited this time?

On the top of the first delta

Excursion 7-4
Alluvial Fan Formation

☐ **1.** Describe the best conditions you found for forming an alluvial fan.

Answers will vary. (The answer should include elements relating to the four variables listed in the text.)

Excursion 7-5
Dunes on the Move

☐ **1.** Predict how the pattern of markings was produced on the face of the dune.

Answers will vary, but should suggest that the sand built up by layering.

☐ **2.** What happens to the sand on the side of the pile facing you? What happens on the other side?

The sand is blown up the slope and is deposited on the far side.

☐ **3.** What agent is preventing the movement of the sand dune in Figure 3?

The vegetation

☐ **4.** Describe the layers in the sand dune. (Are the layers parallel, or do they lie at angles to each other?)

They lie at angles to each other.

☐ **5.** How is the layering in Figure 4 different from the structure of a sand deposit formed in water? (You may want to look back at the water-formed layers in Figure 3-5.)

Water-deposited sand layers do not show cross-bedding. The layers are horizontal.

☐ **6.** Which figure (5 or 6) represents dune-bedding? What evidence is there about changes in wind direction?

Figure 5. The layers lie at angles to each other.

Chapter 8
Waves and Beaches

☐ **8-1.** Which occurred more rapidly, the change from Figure 8-2 to 8-3 or the change from Figure 8-3 to 8-4?

The change from 8-3 to 8-4.

☐ **8-2.** Did the same forces of erosion that brought about the change seen in Figure 8-3 cause the change seen in Figure 8-4? Explain.

Yes. The trees appear undamaged, so it is likely that the wave action of the water, rather than the wind, removed the cottage and the sand.

☐ **8-3.** What effect do the low-energy waves have on the beach? How is this different from the high-energy storm waves crashing into the beach?

The low-energy waves move sand inward, building up the beach. The high-energy storm waves move sand outward, eroding the beach.

☐ **8-4.** Which notch is most affected by the wave action?

The middle notch

☐ **8-5.** What does the space in the crack contain when there is no water washing into it?

Air

☐ **8-6.** What happens at X in Figure 8-11 when a big wave washes into the crack? What effect would this have on the crack?

The air in the crack becomes compressed. This causes the crack to become larger and longer.

☐ **8-7.** What effects do waves have on a coastline like the one shown in Figure 8-8?

The waves expend most of their energy on the headlands, causing erosion of the rock. They then move with less energy into the coves, depositing sand and forming beaches.

☐ **8-8.** How does the arrangement of material in your stream table compare with the diagram in Figure 8-12?

Answers will vary.

Excursion 8-1
Kinetic Energy and Waves

☐ **1.** Where do most waves form? Where does their kinetic energy come from?

Waves begin out in the ocean. Their kinetic energy comes from the wind.

☐ **2.** Why do waves break as they near shore?

Because of the interference of the shallow area with the circular motion of the water particles in the wave.

☐ **3.** Would you expect waves on the Gulf of Mexico to be generally larger, or smaller, than those on the Atlantic Coast? Explain your answer.

The waves would be smaller, because the Gulf of Mexico is smaller in area than the Atlantic Ocean.

1. Some of your students may understand from the text that waves originate long distances out into the ocean. Other students may not have reasoned this from the material in the text. Make this point clear to the students.

Chapter 9
Other Ocean Motions

☐ **9-1.** Based on your study of waves and their effects, what evidence is there of wave action on the shoreline?

There is a sea cave and a sea arch, evidence of a high-tide line, and the beach is steep and curves back away from the rock outcropping in which the cave is located.

☐ **9-2.** Suppose you were standing anywhere on the beach shown in Figures 9-1 and 9-2. In what direction would you see the waves coming?

Straight at you

☐ **9-3.** Describe the pattern of the waves.

The waves are parallel to the shore.

☐ **9-4.** How is the wave pattern different from that observed in Activity 9-1? How is the effect on the beach different?

The wave pattern is curved, creating more erosion at the center of the beach.

☐ **9-5.** Predict what wave pattern you would get with waves entering a wide, curved bay.

A curved wave pattern

☐ **9-6.** What type of wave pattern explains the shape of the bays in the two photographs at the beginning of the chapter?

Curved

☐ **9-7.** Predict what will happen to the shape of the wave pattern when the waves reach the shore.

The waves will be reflected at an angle.

☐ **9-8.** Where (at what height) does most of the erosion take place?

At the water line

☐ **9-9.** How does the change in sea level affect the landscape?

The change in sea level causes undercutting by wave action at more than one height on the face of the cliff.

Excursion 9-1
Building Seashores

☐ **1.** Where does sand build up in your stream table?

On the side of the block facing the incoming waves

☐ **2.** Where is sand building up in Figure 2? (Use the results of Activity 1 in making this prediction.)

At the wharf or jetty

Excursion 9-2
Measuring Sea Level

☐ **1.** How many times does the tide change each day?

Twice

☐ **2.** Is the change in sea level the same each time?

No

Chapter 10
Interpreting a Seacoast

☐ **10-1.** Describe how you think this coastline got to be the way it is. Here are some clues to help you. Notice the rocky outcroppings in the foreground. Do they resemble the results of erosion you've been studying? What about the flat, gently sloping area in the center of the picture? What area of Figure 10-2 does it resemble? Examine that figure, which is an artist's sketch of the same area.

The flat area represents an old wave-cut bench. The sea level has dropped (or the land has been uplifted), and new cliffs have formed. The remains of old sea cliffs, stacks, and arches inland, and old wave-deposited sediments on the flat area, are evidence for the change in sea level.

☐ **10-2.** What does the plaster block do to the waves—does it cause reflection, or refraction?

Refraction

☐ **10-3.** Where does diffraction (curving of the waves) occur?

At the back edge of the plaster block

☐ **10-4.** According to your simulation activity, what might cause this growth at the delta? From which direction would you expect the waves to be coming? (The top of the map represents north.)

The waves would strike the shore from the southwest.

☐ **10-5.** How are wave direction and ocean currents involved in the shaping of the spit shown in Figure 10-6?

Waves strike the coast at an oblique angle. The wave action carries sand along the beach. Longshore currents also carry the sand. If there is a change in direction of the coastline inward so that a point, or headland, is formed, then waves will be bent, or refracted, around the point and lose enough energy to deposit sand. This sand builds up as a curved spit.

☐ **10-6.** Where does sediment collect in an estuary?

At the bottom of the old riverbed

☐ **10-7.** How is the bottom of the fiord different from the bottom of the estuary? Why is it different?

The fiord basin is rounded, with sediments deposited over almost the entire width. The bottom of an estuary has a deep V-shaped channel.

Most of the sediments are found in this deep channel, rather than being spread out over the entire floor of the estuary.

Excursion 10-1
Where Does Beach Sand Come From?

☐ **1.** Why is sand more likely to be formed along a seacoast than in a lake?

Sand is formed by the grinding action of rocks on each other as the result of wave action or fast-flowing currents. These conditions do not occur in a lake.

☐ **2.** What determines the color of sand?

The materials from which the sand is formed

Excursion 10-2
The Formation of Fiords and Estuaries

☐ **1.** Name two possible causes of valley flooding.

The melting of ice sheets at the Poles, the land sinking near the earth's center, or a combination of the two

How Am I Doing?

You probably wonder what exactly you are expected to learn in this science course. You would like to know how well you are doing. This section of the book will help you find out. It contains answers to the Self-Evaluations for each chapter. If you can answer all the questions, you're doing *very* well.

Self-Evaluations are for your benefit. Your teacher will not use the results to give you a grade. But you may want to grade yourself.

Some questions can be answered in more than one way. Your answers to these questions may not quite agree with those in the Answer Key. If you miss a question, review the material on which it was based before going on to the next chapter. Page references are frequently included in the Answer Key to help you review.

On page 53 of this booklet, there is a grid that you can use to keep a record of your progress.

TO THE TEACHER The following sets of questions have been designed for self-evaluation by your students. The intent of the self-evaluation questions is to inform the student of his or her progress. The answers are provided for the students to give them positive reinforcement. For this reason it is important that each student be allowed to answer these questions without feeling the pressures normally associated with testing. We ask that you do not grade the student on any of the chapter self-evaluation questions or in any way make the student feel that this is a comparative device.

The student should answer the questions for each chapter as soon as the student finishes the chapter. After answering the questions, the student should check his or her answers immediately by referring to the appropriate set of answers in the back of the Record Book.

There may be some questions that require planning or assistance from the classroom teacher or aide. Instructions for these are listed in color on the pages that follow. You should check this list carefully, noting any item that may require your presence or preparation. Only items that require some planning or assistance are listed.

You should check occasionally to see if your students are completing the progress chart on page 53.

SELF-EVALUATION 1

If you did any excursions for this chapter, write their numbers here.

____

☐ **1-1.** What was Alfred Wegener's theory of the origin of the continents on the earth?

1-1. States the Wegener theory of continental drift.

____

____

____

☐ **1-2.** What evidence can you give that supports Wegener's theory?

1-2. Identifies evidence supporting the theory of continental drift.

____

____

____

____

SELF-EVALUATION 2

If you did the excursion for this chapter, write its number here.

____

☐ **2-1.** What is an *epicenter?*

2-1. States what an epicenter is.

____

____

____

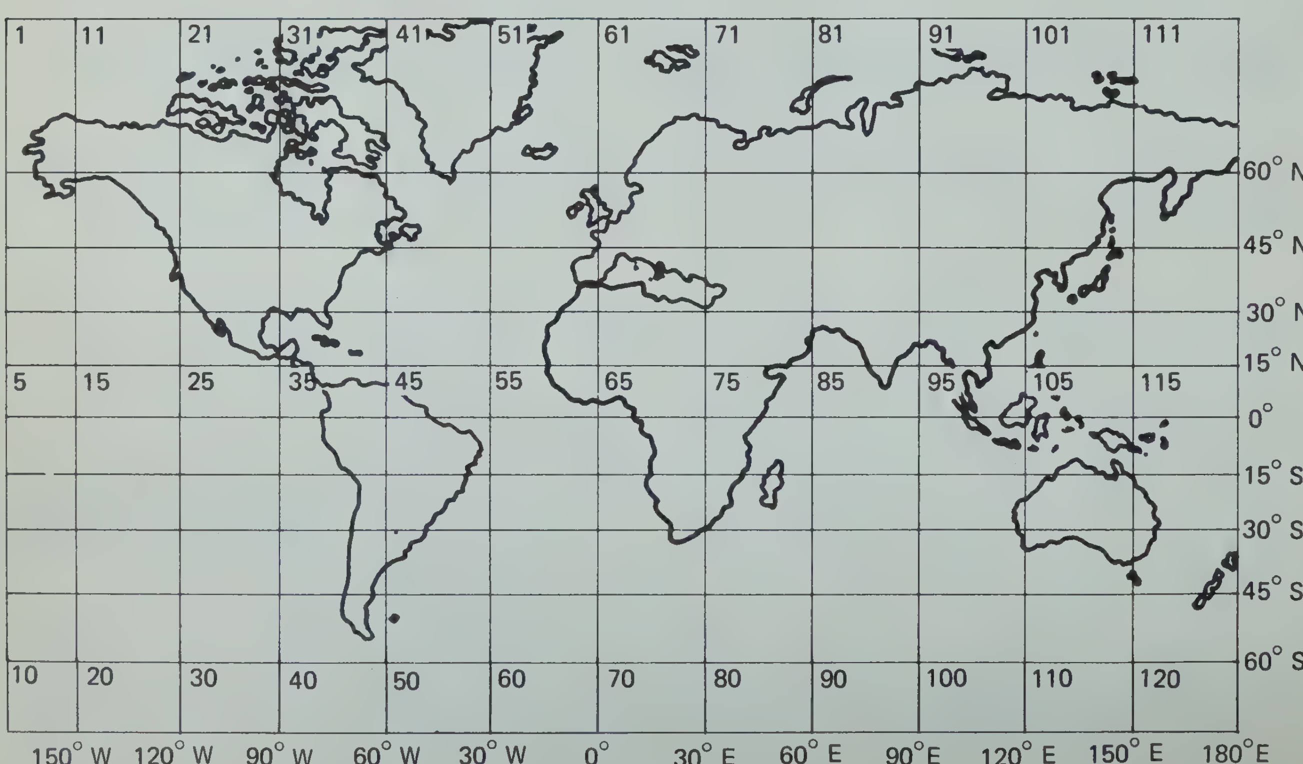
____

____

2-2. Locates earthquakes on maps, using epicenter data.

☐ **2-2.** An earthquake occurs at latitude 40.5° N and longitude 127.3° W. Locate it by placing an X on the map in Figure 2-1.

Figure 2-1



☐ **2-3.** How are earthquake patterns explained?

2-3. Relates earthquake activity and patterns to seafloor spreading.

If you did any excursions for this chapter, write their numbers here.

SELF-EVALUATION 3

☐ **3-1.** Obtain rock samples 13 and 20. Examine each and determine its texture.

3-1. Identifies rock texture as interlocking or noninterlocking.

☐ **3-2.** List three factors that are important in describing a rock's texture.

3-2. Names factors that determine a rock's texture.

☐ **3-3.** Name the three major classes of rock.

3-3. Names three major classes of rock.

3-4. States the conditions under which igneous rock forms.

☐ **3-4.** How do igneous rocks form and what influences the grain size?

3-5. Describes the process by which sedimentary rock forms.

☐ **3-5.** How do sedimentary rocks form?

SELF-EVALUATION 4

If you did the excursion for this chapter, write its number here.

4-1. Identifies the principal processes of mountain-building.

☐ **4-1.** What are the main processes that cause mountains to form?

4-2. States how dome mountains are formed.

☐ **4-2.** How are dome mountains formed?

☐ **4-3.** Match each statement with the type of mountain it describes: **a.** volcanic mountain, **b.** folded mountain, or **c.** dome mountain.

1. Round in shape and found on isolated plains ______

2. Valley and ridges with groups of long, symmetric parallel slopes ______

4-3. Distinguishes between volcanic, folded, and dome mountains.

☐ **5-1.** Place a check mark on the line following any features below that are formed by glacial action.

a. Cirques______

b. Sills______

c. Gullies______

d. Horns______

SELF-EVALUATION 5

5-1. Identifies surface features that are glacial in origin.

☐ **5-2.** How does glacial carving occur?

______

______

______

5-2. Describes the process of glacial curving.

☐ **5-3.** Explain how glacial carving can continue without the glacier advancing.

______

______

______

______

______

______

5-3. Describes conditions affecting the advance of ■ glacier.

SELF-EVALUATION 6

If you did the excursion for this chapter, write its number here.

6-1. Describes characteristics of river systems.

☐ **6-1.** What two conditions must exist for a river system to originate?

6-2. Differentiates between kinetic energy and potential energy of river water.

☐ **6-2.** What condition determines the potential energy of river water? the kinetic energy of river water?

6-3. Identifies factors that increase a river's kinetic energy.

☐ **6-3.** List several factors that can increase the kinetic energy of a river.

SELF-EVALUATION 7

If you did any excursions for this chapter, write their numbers here.

☐ **7-1.** Name three features that form when a river's kinetic energy has been reduced.

____

____

____

7-1. Identifies depositional features resulting from reduction of a stream's kinetic energy.

☐ **7-2.** Explain why particles deposited along a stream's path vary in size.

____

____

____

____

____

7-2. Explains the gradation in particle size found in stream deposits.

☐ **7-3.** How do gullies form?

____

____

____

____

____

7-3. Explains how gullies form.

☐ **7-4.** What is headward erosion?

____

____

____

____

____

7-4. Explains headward erosion.

SELF-EVALUATION 8

If you did the excursion for this chapter, write its number here.

____

8-1. Relates type of shoreline change to wave energy that produces it.

☐ **8-1.** Listed below are three changes that occur along a shoreline. For each change, indicate whether it is evidence of high-energy wave action or low-energy wave action.

a. Gravel and solid rock exposed where sand was once located ________________

b. Accumulation of sand offshore—a bench ________________

c. Gravel and solid rock covered by sand ________________

8-2. Predicts effect of a hurricane on a beach.

☐ **8-2.** Is a hurricane more likely to deposit huge amounts of sand and shells on a beach or to carry beach material out to a bench offshore?

8-3. Identifies features associated with rocky or steeply inclined shores.

☐ **8-3.** Name three features commonly associated with rocky or steeply inclined shorelines.

____

____

____

SELF-EVALUATION 9

If you did any excursions for this chapter, write their numbers here.

____

9-1. Explains mechanism for the formation of a sand beach.

☐ **9-1.** Are sand beaches developed as a result of high, or low, wave energy?

____

☐ **9-2.** Under what natural shoreline conditions does diffraction and refraction of waves occur?

9-2. Identifies shoreline conditions that cause refraction and diffraction of waves.

____

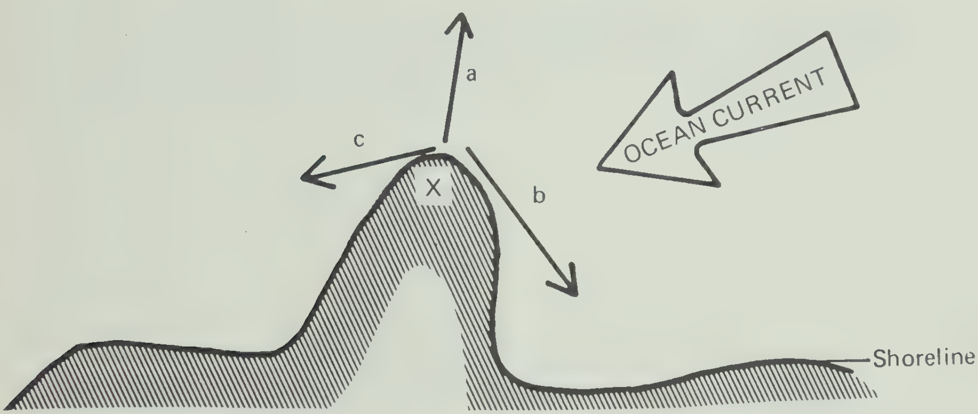
____

____

☐ **9-3.** The diagram below shows a coastline of sand beaches, with the direction of ocean current marked. Identify the arrow that best describes the direction that sand eroded from X will travel.

9-3. Identifies effects of longshore drift on beaches.

Figure 9-1



☐ **9-4.** What does the height of undercutting of a cliff by wave action indicate?

9-4. Identifies wave-cut benches as evidence of erosion influenced by tides.

____

____

If you did any excursions for this chapter, write their numbers here.

SELF-EVALUATION 10

____

10-1. Describes how sandbars and spits are formed.

☐ **10-1.** How are sandbars and spits formed?

10-2. Differentiates between fiords and estuaries in terms of the processes by which they were formed.

☐ **10-2.** What is the difference between a fiord and an estuary?

Answer Key

SELF-EVALUATION 1

1-1. All continents were once joined together in one large landmass, which broke apart into separate continents.

1-2. The jigsaw-puzzle fit of the continents, the location of glacial drift, and grooves of the same age on matching continents are strong evidence that supports Wegener's theory.

SELF-EVALUATION 2

2-1. An epicenter is a point on the surface of the earth below which the most active portion of an earthquake is located.

2-2.

2-3. The earth's crust is separated into plates. Earthquakes occur at the boundaries between these plates, when they slide toward or away from each other.

SELF-EVALUATION 3

3-1. Sample 13 is noninterlocking. Sample 20 is interlocking.

3-2. Answer should include three of the following: visibly cemented grains, interlocking grains, grain size, and arrangement of grains

3-3. Igneous, metamorphic, and sedimentary

3-4. Igneous rocks generally form under conditions of high temperature. Grain or crystal size is affected by the rate at which the rock material cools and the amount of pressure applied at the time. The slower the cooling rate and the greater the pressure, the larger the crystals that are formed.

3-5. The process of forming sedimentary rock begins where finely divided rock (or shell) collects. The process is completed as a cementing agent, such as iron compounds, cements these particles together.

SELF-EVALUATION 4

4-1. Uplift by faulting, folding, and volcanic action

4-2. Dome mountains are composed of coarse-grained igneous rock formed deep in the earth's crust, and subsequently uplifted. Softer surrounding rock was eroded away, leaving the dome exposed.

4-3. 1-c; 2-b

SELF-EVALUATION 5

5-1. Check **a** and **d.**

5-2. The pebbles and boulders embedded in the ice grind a path through the surface over which they move.

5-3. When the formation of new ice at the head of a glacier equals the rate of melting at its foot, the foot remains at the same place. Rock and ice slowly move down toward the foot, replacing the melting ice. Glacial carving accompanies the motion.

SELF-EVALUATION 6

6-1. A river originates in an area's highest point. There must be sufficient rainfall.

6-2. The potential energy of river water depends upon the height of the water. The greater the vertical distance through which the water ultimately falls, the greater the potential energy. The river has the greatest kinetic energy at the point where the water moves the fastest.

6-3. The three principal means of increasing the kinetic energy of river water are to increase the volume of water flowing in the river (rain or melting snow), to remove obstacles from the water's path, and to increase the vertical distance the water must fall.

SELF-EVALUATION 7

7-1. Answer could include any three of the following: alluvial fans, sandbars, deltas, mud bars, spits.

7-2. As a stream loses kinetic energy, the larger and heavier rocks or particles drop out first. Downstream, as the stream continues to lose kinetic energy, the smaller particles drop out.

7-3. Gullies form as rainwater erodes away soft or loose material and carries it downstream. The gullies get steeper, causing the water to flow faster. Erosion speeds up, and the gullies grow larger.

7-4. Headward erosion is a process by which the erosion of a waterfall or gully moves upstream. As the water flows over the falls or rapids, rock and soil are carried away fastest from the lip and foot. Therefore the falls itself seems to move upstream over a time.

SELF-EVALUATION 8

8-1. **a.** high; **b.** high; **c.** low

8-2. Hurricanes are more likely to carry material away from a beach and deposit the material underwater in a bench offshore.

8-3. Arches, caves, and benches

SELF-EVALUATION 9

9-1. Low wave energy

9-2. Bending of waves by refraction is due to shallow water slowing down the crests. Refraction is the bending of a wave train at a barrier.

9-3. **c**

9-4. Erosion taking place between high and low tides

SELF-EVALUATION 10

10-1. Sandbars are deposits of sand that have built up as a result of currents or wave action. Sand spits are long, narrow sandbars that project into the sea from the mainland.

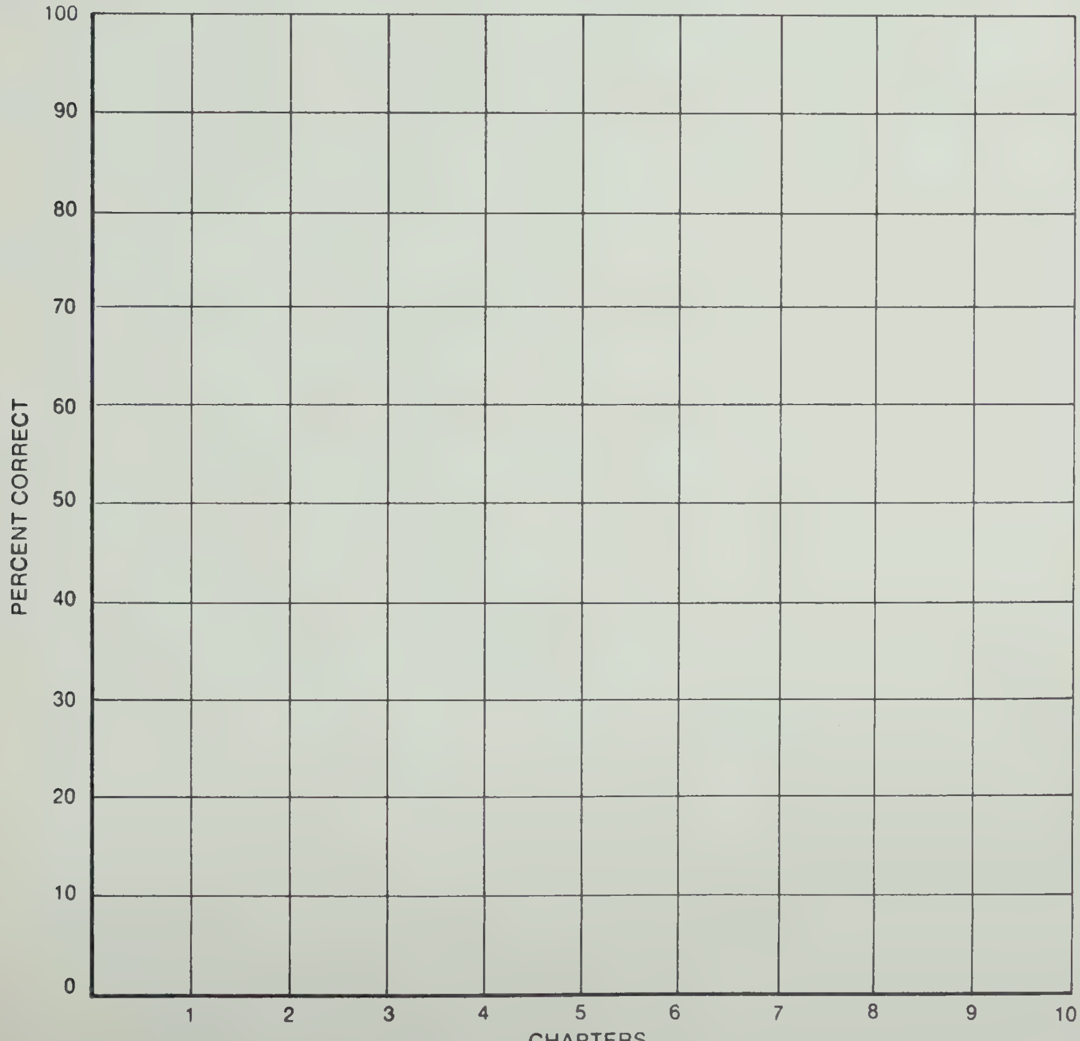
10-2. A fiord is a flooded, ice-carved valley. An estuary is a flooded, river-carved valley.

My Progress

Keep track of your progress in the course by plotting the percent correct for each Self-Evaluation as you complete it.

$$\text{Percent correct} = \frac{\text{Number correct}}{\text{Number of questions}} \times 100$$

To find how you are doing, draw lines connecting these points. After you've tested yourself on all chapters, you may want to draw a best-fit line. But in the meantime, unless you always get the same percent correct, your graph will look like a series of mountain peaks.



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